The Eleventh Regional Wheat Workshop For Eastern, Central and Southern Africa

Addis Ababa, Ethiopia
18–22 September, 2000

Sponsored by:

CIMMYT/CIDA Eastern Africa Cereals Program
CIMMYT Wheat Program
CIMMYT/EU MWIRNET/RSA Project
CIMMYT Economics Program
Ethiopian Agricultural Research Organization

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On the cover:	Upper left:	Land preparation by "maresha" (Debre Zeit, Ethiopia).
	Upper right:	Farmer Research Group assessing wheat genotype by management level participatory trial (Debre Mewi, Ethiopia).
	Lower left:	Farmers threshing wheat (Adet, Ethiopia).
	Lower right:	The end product – home-made "dabo" (Kulumsa, Ethiopia).
		[Photos provided by Douglas Tanner, CIMMYT]

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Countries participating in the Eleventh Regional Wheat Workshop for Eastern, Central and Southern Africa.

A WELCOME ON BEHALF OF THE CIMMYT BOARD OF TRUSTEES

Johan Holmberg

Ambassador of Sweden to Ethiopia and Vice Chair, CIMMYT Board of Trustees

Dear participants and friends,

I may be an ambassador now, but my background is in agriculture and I worked with rural development in Ethiopia during the 1970s. I am here today as a representative of the CIMMYT Board to welcome you all to this workshop. Let me say at the outset that I am proud to represent CIMMYT. This is, as most of you know, one of the oldest and also largest of the CGIAR centers. Allow me on this occasion to brag a little about CIMMYT. While I may be partial, I have reason to believe that it is one of the very best CGIAR centers in terms of scientific output. It certainly is one of the leading CGIAR centers in terms of biotechnology and it is in the forefront as regards policies on IPRs. Given its mandate on maize and wheat it is what is called a commodity center and as such has a better sense of purpose than other centers with less clear mandates. World class research is being conducted at CIMMYT. Recently, CIMMYT received a prestigious prize for its research on high-protein maize. I am pleased that you can come here and share some of CIMMYT's results.

I already mentioned that I lived in Ethiopia during the 1970s. In fact, I lived here for five years working in agriculture and in the very area that you will visit tomorrow, the Arsi region some 170 km from here. I often get the question how Ethiopia of today compares with the Ethiopia that I knew 25 years ago. What I will do this morning is to try to answer that question from the perspective of agricultural development.

It pleases me enormously that you will all be making a field trip tomorrow to the Kulumsa Research Center. In the bad old days, Kulumsa was an Italian farm; there are still Italian writings visible on some of the buildings. Later, in the 1960s, Swedish experts identified Chilalo awraja in Arsi region as suitable for a new experimental rural development project trying what were then very innovative ideas, derived from the Comilla Academy in Bangladesh, to integrate different development activities designed to reduce rural poverty. This project started in 1967 after one year of preparation. From the outset, it developed Kulumsa as a seed farm and research station. When you go there tomorrow, most of the buildings that you will see were constructed as part of the Swedish-supported Chilalo Agricultural Development Unit, or CADU project. If you go on to Asella, you may see the project center with many more buildings - all built as part of CADU.

The Swedes left the project in the late 1980s. By then, there were considerable problems arising out of the then government's policy of promoting collective approaches to agriculture, including forcing farmers to move into collective villages. It had become very difficult to assess project results and staff were very disenchanted. I think it is fair to say that it was with a certain relief that the Swedes terminated their support, but we were eventually replaced by Italians. Earlier this year, I participated in an OECD-sponsored evaluation of the large Italian aid program to Ethiopia. I was pleased to note that the Italian support in Arsi not only continues, but is regarded as one of the best projects in the Italian portfolio today!

I said that CADU was an integrated rural development project. There has been much debate on the merits of such integrated projects and I will not go into that now. But I will say that I strongly believe that the basic concept remains valid. Farmers have multiple needs. It makes little sense to promote higher agricultural yields, if they cannot get their produce to market. They need water, soil conservation, trees, support for their animals, and so on. And while all of that need not happen under the same roof, as it were, it must be attended to, otherwise bottlenecks will soon appear.

And that takes me to one of the major accomplishments of the project that you will visit tomorrow. Because of its immediate success, to which I will return in a moment, CADU spawned a number of similar projects elsewhere in Ethiopia. There was one around Debre Zeit, in Ada wereda, supported by USAID. There was one in Welayta supported by the World Bank called WADU. Then there was TAHADU up in Tigray close to the border with Eritrea. Most importantly, there was the nation-wide Minimum Package Program supported by the World Bank and a host of bilaterals that extended the basic features of these so called maximum package programs throughout the country. All of these programs basically were closed down or radically changed during the 1980s. But to this day there is recognition in Ethiopia that rural development is a process of promoting a set of co-ordinated actions ranging from agricultural research to road construction. The fact that this approach is so firmly grounded in Ethiopia derives, I believe, from the success of the package projects started in the 1960s, of which CADU was the first.

I will not bore you with figures and data from a project started over 30 years ago - it would be easy for me to wax sentimental and get carried away. However, the number of credit recipients increased from 189 in 1967/68 to 57,000 in 75/76 and on to some 90,000 in 1982/83. What the project did was to essentially promote green revolution type technology, principally the application to DAP fertilizer to wheat, maize and barley and the promotion of improved seeds of those crops. The need for agricultural research was recognized from the outset. At the research station Kulumsa that you will visit tomorrow, varieties primarily of wheat were developed that have remained to this day, Laketch and Romany being two of them. There was in this project a direct chain from research to agricultural extension, farm input supply and credit, and finally marketing as part of which the credit was repaid. Credit repayment rates were in the order of 95 per cent which naturally indicates that the innovations were profitable to farmers.

CADU did very careful crop yield assessment surveys, and the following chart shows wheat yields in the project area prior to the project in 1966 and in three awrajas (counties) in Arsi from a survey carried out in 1981. You note that the yield in Chilalo was already then, 19 years ago, at 16.3 qt/ha much higher than today's national average wheat yield which is in the order of 12 qt/ha . Chilalo was then and still is today one of the prime breadbaskets of the country and with regard to wheat probably the most favored area, something you may wish to keep in mind when you go there tomorrow.

I believe that you are all aware that Ethiopia in many respects offers extreme problems and opportunities, even as compared to many other African countries. Ethiopia ranks in place 171 out of the 174 countries listed in UNDP's Human Development Index; in other words, there are only three countries in the world that are poorer than Ethiopia. Population grows at some 3% per year and 85% of that population derives its livelihood from small-scale agriculture.

The urban population is only 16.7% and the country basically lacks urban growth centers that can absorb labor surpluses from the countryside. Industry makes a contribution to GDP of only 6.7%, the smallest of any country in the world. The topography is dramatic with agriculture being practiced at altitudes ranging from 1,000 to almost 4,000 m a.s.l. providing strong challenges to agricultural research and extension. Average road density is only 0.44 km per 1,000 population, one of the lowest in Africa. This means that 75% of all farms lie more than a half-day walk from an all-weather road, or, put differently, three-quarters of all farms cannot be reached by car. Nearly two-thirds of rural holdings are less than 1 ha.

All of this, of course, means tremendous challenges for the agricultural sector. Few countries are as dependent on raising productivity in agriculture as Ethiopia. Few countries are as sensitive to setbacks affecting that sector as Ethiopia, be they caused by the vagaries of the climate or by policy failure. The government is well aware that agriculture is the engine of growth in the Ethiopian economy. However, agricultural growth rates are still inadequate when compared to the rate of growth of population. Production levels fluctuate with rainfall. Growth in the sector has declined in recent years due to bad weather conditions. Some 10 million people are this year requiring emergency food aid.

Key to agricultural development today, as was the case 25 years ago, is land policy. While I lived here the revolutionary government in 1975 proclaimed what was then called the most radical land reform anywhere in the world which in one bold stroke abolished privately owned land saying that all land belongs to the state, nationalized commercial holdings into state farms, and gave all peasants usufruct rights to land under the slogan "land to the tiller". In the 25 years that have passed since then the country's population has doubled. There is now a desperate shortage of arable land. Holdings are getting smaller and smaller, indeed fully 45% of all households are said to farm less than 0.5 ha. There is a desperate need to consolidate farm holdings and get people off the land into alternative employment opportunities. As you travel around the country, you frequently see large fertile areas suitable for modern, mechanized agriculture which are fragmented into tiny plots each being cultivated by a man using oxen and a wooden plough. Surely this is one of the major factors behind Ethiopia's chronic food insecurity. The population pressure has made this issue much more acute than it was 25 years ago, and it has therefore become politically sensitive as well. But I believe the government understands that this issue requires attention.

The other aspect is, of course, the need to raise yields on farmers' fields. I am aware of CIMMYT papers showing the rising yield trends of bread wheat cultivars released in Ethiopia since the 1950s. But the number of farmers using improved wheat varieties is still to this day tiny, relative to the total farming population; remember that I just said that 75% of rural households remain largely inaccessible. There has been an increase in cereal output in the last decade, but that has largely been due to expansion of the area cultivated, often at the expense of increased soil erosion and reduced fallow. Clearly, this is not sustainable and does not bode well for food security in the long term.

A major characteristic of modern farm input use in Ethiopia is the dependence on only one input, fertilizer. Again, this is probably a consequence of the package programs of the 1970s which arguably promoted fertilizer use, as such successfully, but often at the expense of improved seeds. Fertilizer use increased by nearly 10% per year during 1991-98, one reason being that unlike in other African countries fertilizer was not seriously affected by the removal of subsidies. But the potential of fertilizer is not being fully exploited. The seed

quality is often low which reduces possible yield increases. Shortcomings in the extension service often mean that farmers do not apply the right quantities. Having invested in fertilizer, farmers are usually too poor to afford other modern inputs, such as pesticides, despite rampant insect and disease problems. Further, fertilizer marketing is marred by regional monopolies and an absence of competition.

The regionalized administrative structure in the country has made important progress relative to 25 years ago. The constitution now gives the country a federal structure where the regional states have considerable autonomy in designing and implementing development interventions. This has addressed perhaps the major shortcoming of the old package programs, namely that they were independent entities with minimal ties to the local administration. I remember that in CADU we regarded the local administration as crooked and corrupt and tried to avoid it as far as possible. Obviously that is not sustainable over the long-term. Today, the local administrations are much more in control of development. Projects for rural development are implemented through the regional authorities at various levels, representing a vast improvement.

What this means is that at the regional state level there are agencies for farm credit, agricultural extension and agricultural research. Capabilities in this regard vary from one regional state to another, as might be expected. But this structure gives a stronger sense of local ownership and better possibilities of adaptation to the varying local circumstances than was the case 25 years ago.

For example, most regional states now have their own micro-finance credit institutions, often using a group approach to extending credit. While many of these institutions are struggling with difficult issues of finance and operating costs, their lending is expanding and loan recovery rates are surprisingly high, e.g., in Amhara Regional State, recovery rates are consistently claimed to be close to 100%. Despite existing problems, there seems to be in place a sustainable structure for the provision of farm credit.

The extension system appears to be more problematic. It would seem to have expanded too fast with regards to quantity at the expense of quality. In the Minimum Package Program 25 years ago, there was a strict structure with one agricultural extension agent for about 2,000 farmers, five extension areas located adjacent to one another along an all-weather road, and one supervisor for one such zone with five extension agents. An extension agent usually had completed 12th grade in school and in addition had studied for two years at an agricultural college. Today, there are altogether 13,651 so-called development agents, in addition to 935 home agents, and 1,178 supervisors in the extension system. This means over 12 agents per supervisor, too high a number for effective supervision.

A development agent is expected to serve 700-1,000 farmers. But he/she is less well trained than the extension agents of old: today an agent often has less than 12 years of schooling and receives specialized training for only nine months. The development agents are frequently required to perform work unrelated to agriculture which reduces the time they have for their regular tasks. Often agents lack practical farming knowledge and specific information about the technologies that they are asked to promote. The validity of their advice can therefore often be called into question. The expansion of the extension service has been carried out in the interest of reaching as many farmers as possible, an as such laudable egalitarian policy

first introduced by the previous socialist government. But there is no doubt that extension today is a weak link in the chain of services promoting increased agricultural productivity.

But the extension service is also hampered by the weaknesses of the seed multiplication system and of research. Less than 2% of all farmers use improved seed. Besides, the quality of improved seeds is generally low. One of the major problems is loss of genetic quality due to long periods of repeated use. The research system is weak and unable to replace old varieties with new ones at the right time. Erratic rainfall has in places affected seed production, and irrigation is insufficiently developed in support of seed production. There is a national parastatal company responsible for seed multiplication and distribution, but its capabilities are totally inadequate relative to the needs. The only international seed company operating in the country, Pioneer, produces only hybrid maize seed. No other private seed producer is operating in the country. In Amhara Regional State, promising approaches have been made to contract private farmers to multiply seed, but the bottleneck then becomes the shortage of basic seed. Clearly, this is an area with considerable room for improvement.

This brings me to the shortcomings in the agricultural research system. Here I need to weigh my words carefully since I am acutely aware than I am talking to many representatives of that system. I believe the organizational changes brought about in research since 25 years ago have been on the whole conducive to making the system more responsive to the great locational variability that is characteristic of Ethiopian agriculture with a national umbrella organization coupled with attempts to strengthen research at the regional state level. But clearly the resources available to the system are far from adequate. The latest figures I have are from 1993/94. In that year, research expenditure in Ethiopia was equivalent to only 0.2% of agricultural GDP which is far below the recommendation from the CGIAR institute ISNAR - that 2% of agricultural GDP be invested in agricultural research. Lack of funds creates difficulty in retaining qualified staff and creating the essential critical mass of scientists. Since private agricultural research is non-existent in Ethiopia, those who leave the national research system either join other professions or go abroad. At a recent well-attended conference on economic development in Ethiopia, the need for increased attention to agricultural research was scarcely mentioned. This begs the question of whether the importance of more investment in this area is well understood by decision-makers.

Dear friends and colleagues,

It is time to wind up. You only need to be a casual reader of newspapers to understand that Ethiopia is facing serious problems with regards to national food security. While important improvements have been made over the 25 years or so during which I have been able to monitor agricultural development in this country, many difficult issues remain. I have tried to give you some perspective for the visit that you will make to Kulumsa tomorrow. Once more, most welcome to this workshop which I hope will be interesting and productive. I thank you.

CIMMYT'S NEW APPROACH TO ADDRESS WHEAT PRODUCTION CONSTRAINTS IN MARGINAL AREAS - GLOBAL PROJECT 5

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ABSTRACT

Recently, CIMMYT has instituted a project-based management system (PBMS) to better organize and integrate its research activities. The aim of PBMS is to increase our research effectiveness and efficiency by enhancing cross-program and collaborative partner interactions through multidisciplinary research. Global Project 5 (GP5) — "Increasing Wheat Productivity and Sustainability in Stressed Environments" — emphasizes germplasm improvement, production systems and natural resource management for marginal environments. It has a strong strategic research component and consists of a multi-disciplinary team of scientists. The project capitalizes on synergies resulting from an integrated, interdisciplinary focus on major stresses across crop commodities. Sub-projects 1 to 3 concentrate on crop enhancement targeting moisture, temperature, and nutrient stresses, respectively. Sub-projects 4 to 6 generate knowledge and methodologies for crop improvement and management while integrating applied and strategic research within sustainable wheat production systems. The concepts and strategies of GP5 are developed from recent research data, linking strongly with current "state-of-the-art" breeding.

INTRODUCTION

Borlaug and Dowswell (1997) observed, "The only way for agriculture to keep pace with population and alleviate world hunger is to increase the intensity of production in those ecosystems that lend themselves to sustainable intensification, while decreasing intensity of production in the more fragile ecosystems." By 2020, "The world's farmers will have to produce 40% more grain . . . most of which will have to come from yield increases" (Pinstrup-Andersen *et al.*, 1999). Projecting diminishing per capita land and water resources during the coming century, recent studies predict production must increase by 1.6% per annum over the next 20 years to meet the increasing demand for wheat on the global level. About half the required production increases are expected to come from crop management research (CMR), with crop improvement required to contribute nearly 1% per annum. This poses an immense challenge to wheat improvement research, given that in recent years genetic gains of such magnitude have been infrequently realized (Byerlee and Traxler, 1999; Calderini *et al.*, 1999).

About 60% of the wheat area in the developing world – 75 million hectares – are affected by abiotic stress, with approximately 45 million hectares subject to moisture stress, and temperature extremes and nutrient stresses affecting a similar acreage. Impact from agricultural research can be seen in farmer's fields and production statistics (Byerlee and

Moya, 1993). Adoption rates indicate that modern varieties grown in dry regions are approaching those in more optimal irrigated and high rainfall areas. After an initial lag, adoption rates in drought prone rainfed areas in Argentina, Pakistan and Syria are above 90%. Data from 1998 exhibits a similar situation in North Africa with adoption rates between 80% and 90% for Morocco and Tunisia. Only Algeria lacks behind with adoption rates of modern varieties below 50%.

Increasing and stabilizing production in abiotically stressed environments poses one of the greatest challenges for agricultural research in the 21st century. These environments are fragile, highly variable and crop yields are often non-economic due to deteriorating natural resources. Constraints are intrinsic: gains for agronomic inputs decrease with increasing moisture stress. Translated to crop improvement, genetic gains are hard to measure and therefore difficult to achieve. This situation implies that over-proportional genetic gains and production increases are required to change this disparity, frequently even to reach economic production levels (low and unstable farm-level yields and aggregate regional production from rainfed environments).

Another complication is the high variability of abiotic stress environments. Singh and Byerlee (1990) analyzed wheat yield variability in 57 countries over 35 years. Yield variability was measured by calculating coefficients of variation of yields around linear trends. Amount and distribution of rainfall was the predominant factor influencing yield variability: countries in which half the wheat was sown in dryland conditions experienced twice as much variability as countries in which wheat is mostly grown under well watered conditions. Yield variability also tended to be higher in warmer subtropical countries due to heat stress. Genotypes selected in one year under severe stress often perform poorly in subsequent years when moderate stress may occur. Consequently selection gains tend to cancel each other out because genotypes are unlikely to be superior over the wide range of production conditions experienced. These changing environmental indices and subsequent low realized heritabilities mask genetic potential, while adaptive traits and trait combinations are complex and difficult to identify.

Many cereal breeders working in dry environments long ago gave up attempting to screen for drought tolerance *per se*. The genetics of drought tolerance is poorly understood and the highly variable nature of rainfall in these environments makes genetic progress for drought tolerance extremely difficult, as drought patterns are not consistent among years. In addition, many biotic and abiotic factors are frequently misinterpreted as expression of drought tolerance. For example, plants tolerant to nematodes or micro-nutrient imbalances, may be selected as drought tolerant by the plant breeder, simply because they have healthier root systems. Some of the key constraints confronting breeders in stress environments are listed in Table 1. Breeders have therefore concentrated on improving tolerance to those factors, particularly diseases, for which they have known and repeatable variation.

To improve genetic gains and realize production increases in stressed environments, researchers need to:

- Better characterize environments using physical parameters and probability ranges for climatic variables to identify relevant traits and apply weighted selection indices;
- Identify morpho-physiological drought adaptive traits and molecular markers with higher heritability than yield;
- Develop more efficient screening and selection methodologies and tools;

- Develop and implement sustainable crop management practices.

In January 1998, CIMMYT instituted a project-based management system (PBMS) to organize research under its Medium Term Plan. The aim of PBMS is to increase research effectiveness and efficiency by enhancing cross-program interactions and multidisciplinary research including improved collaborative opportunities with CIMMYT's partners. Global Project 5 (GP5) – "Increasing Wheat Productivity and Sustainability in Stressed Environments" -- emphasizes germplasm improvement, production systems and natural resource management in marginal environments. It has a strong strategic research component and consists of a multi-disciplinary team of scientists.

GP5 employs a concept different from the traditional crop commodity oriented approach with individual crop programs (bread wheat, durum and triticale) addressing applied and strategic research. The project capitalizes on synergies resulting from an integrated, interdisciplinary focus on major target stresses across crop commodities. Sub-projects 1, 2, and 3 concentrate on crop enhancement for the major stress areas – SP1 moisture stress, SP2 temperature extremes, and SP3 nutrient stress and pH extremes. SP 4, 5, and 6 generate knowledge and methodologies required by integrating applied and strategic research (crop physiology, crop management, biotechnology, biometrics, IWIS/International Testing, GIS). This paper outlines the project structure and some recent findings.

The Structure Of The PBMS For Improving Productivity In Abiotically Stressed Environments

(1) Development of drought, temperature and pH tolerant wheat and triticale germplasm

Expansion of genetic variability:

To build upon past successes in the development of drought tolerant wheat, it will be necessary to expand the genetic variability currently available in both the hexaploid and tetraploid gene pools. Among the hexaploid bread wheats, new and useful variation is being exploited through the production of synthetic wheats. These wheats result from crosses between the two putative progenitors of wheat (*Aegilops tauchii* and *Triticum durum*) with subsequent chromosome doubling. Historically, this cross has probably occurred on few occasions and consequently, there has been limited sampling of the genetic resources of these two species in the development of bread wheat. The *A. tauchii* accessions currently available have been collected in some of the harshest environments on earth and have evolved over thousands of years in conditions of periodic drought, heat, flooding and frosting. This material should also be more amenable to the identification and application of molecular marker technology as the frequency of polymorphisms can be expected to be considerably higher than that found in conventional wheat. The *T. dicoccum* wheats and tetraploid landraces provide useful potential sources of variation that can also be further exploited. Figure 1 outlines the impact on bread wheat breeding for drought tolerance of germplasm derived from crosses with synthetic and tetraploid germplasm at CIMMYT. Crosses with synthetic and tetraploid parents give respective genetic gains 4% and 3% greater than crosses among bread wheat alone.

Refinement of selection environments to better predict drought tolerance *per se*:

The variable nature of rainfall leads to low realized heritability for grain yield during the selection of segregating generations for drought tolerance in most dry environments. Large Genotype x Year interactions frequently obscure genetic gains. The more repeatable the selection environment, the greater the genetic gain. The CIMMYT wheat program utilizes a dry, arid location near Cuidad Obregon in north-western Mexico (27°N, 40 m a.s.l.) to screen for drought tolerance *per se*. The heritability of selection in this environment is high, ranging between 0.5 and 0.7 year-to-year. Germplasm is developed by alternating the selection of segregating generations between this dry environment and a high rainfall site in the central Mexican highlands (19°N, 2640 m a.s.l.). The strategy was developed to combine drought tolerance with input responsiveness and resistance to the foliar diseases.

However, whilst this methodology has been successful in providing elite drought tolerant germplasm to many countries, the question remains 'can this selection process be modified or fine tuned to better reflect the target environments in the NARS?' A trial consisting of bread wheat, durum wheat and triticale genotypes, already tested extensively internationally, has been grown using various moisture stress scenarios in Obregon. Moisture stress was generated using gravity-fed, overhead sprinkler and drip irrigation regimes. The results from 1998-1999 and 1999-2000 are presented as a dendrogram in Figure 2. The initial results indicate that the simulated "Mediterranean" or post-anthesis stress (identified as ME4A in Figure 2) simulated using either gravity, sprinkler or drip irrigation in Obregon does not cluster well with most global test locations. Similarly, the gravity fed continuous stress trials from Obregon (Gravity ME4C) which represent residual moisture stress environments and the optimally irrigated drip experiment (Drip ME1) tended to cluster with the Obregon generated ME4A treatments only. However, late sowing (Gravity heat), pre-anthesis generated drought (Sprinkler ME4B) and severe stress generated using drip irrigation (Drip ME4C) demonstrated closer associations with global drought locations. These results indicate association among environments on the basis of their correlated ranks, it does not preclude the selection of high yielding, well adapted germplasm from CIMMYT's elite nurseries traditionally selected in Obregon using gravity fed ME4A and C conditions.

Analysis of the international trial data for bread and durum wheat indicates significant G x E interactions among global testing locations (De Lacy *et al.*, 1994; Abdalla *et al.*, 1996). To better understand the underlying causes of G x E in key wheat growing stress environments, an investigative performance nursery has been assembled. This nursery or International Adaptation Trial (IAT) contains probe genotypes that differentiate most major soil borne stresses, both biotic and abiotic. The aim of the IAT is to:

- Target environments subject to drought, heat and low pH in client NARS countries;
- Identify production constraints and relevant traits to better tailor germplasm to these areas;
- Identify and verify morpho-physiological and molecular markers;
- Examine the relevance of Mexican breeding/testing locations to stress patterns in client countries;
- Investigate agronomic practices, trial designs and biometrical techniques. The results generated from the deployment of the IAT during the next three years will enable breeders from all participating countries to better target their crossing programs. Data can also be used to improve and validate both genetic and agronomic simulation models.

Progress in breeding for phosphorous use efficiency has been significant over time (Ortiz-Monasterio, unpublished data) (Figure 3). Whilst genotype response to applied P has been significant over time, the newer cultivars also outperform their predecessors at low levels of P. Similar patterns of response have also been observed for nitrogen (Ortiz-Monasterio *et al.*, 1997).

(2) Determination of the physiological and genetic basis for abiotic stress tolerance and the development of efficient selection methodologies

Identification and inheritance of drought adaptive traits:

To improve genetic progress for drought tolerance the existing variation must be properly characterized and the physiological, morphological and genetic basis understood. While a number of traits or trait combinations have been proposed for indirect selection (Marshall, 1987; Richards and Condon, 1994), there has been little progress in the practical application of selection for these traits in wheat breeding programs. This has been largely due to the cumbersome and time-consuming nature of most assays for these characters. However, an exception is canopy temperature depression (CTD), a measure of the difference between canopy temperature and ambient temperature, is being successfully used at CIMMYT to select genotypes tolerant to heat (Amani *et al.*, 1996; Reynolds *et al.*, 1994).

The previous section deals with the quantification of repeatable genetic variation, once this has been determined, those traits or trait combinations contributing to improved performance can be identified. Quantification of differences among drought tolerant and intolerant populations in repeatable environments will be an important first step in understanding both the physiological and molecular basis of drought tolerance.

Development and implementation of molecular strategies:

Once key areas of the genome are identified that contribute to drought tolerance under a particular set of environmental conditions, the plant breeder can then begin combining adaptation to various types of drought. The development of QTLs may also identify regions of the genome that are constant to all moisture limiting conditions. To date, this technology is not available to the wheat breeder, however QTLs offer potential for the enhancement of drought tolerance per se in wheat improvement programs around the world. At CIMMYT two mapping populations combining drought tolerant and intolerant parents are currently being assessed with the view to identifying possible QTLs. However, of perhaps greater significance will be the application of functional genomics. Examining proteins produced by different loci in different environments will allow breeders to optimize their crossing strategies and in time, may lead to the identification of key genes responsible for both specific and general adaptation to drought.

Among the technologies currently available, DNA finger printing of key germplasm once characterized for drought tolerance offers the most potential. Breeders could more accurately estimate coefficients of parentage and increase the efficiency of their crossing programs. Finger printing could also provide useful information on those regions of the genome contributing to drought tolerance.

(3) Develop and disseminate sustainable crop and resource management strategies to increase productivity and stability of rainfed wheat systems

To realize genetic gains in drought tolerance in farmer's fields, suitable agronomic practices must be implemented. Moisture conservation practices such as reduced or zero tillage and stubble retention require a change in infrastructure. Many farmers, particularly those from developing countries, are unable to cope with the associated expense of implementation of these new techniques, however, the interaction of tillage regime x genotype will be very important in realizing significant gains in productivity in dry environments. Other practices such as shifting cultivation or periods of fallow and water harvesting will also better utilize available moisture. This sub project aims to: 1) disseminate crop management solutions to intermediate users (NARS, NGOs) and farmers; 2) advise breeding programs re appropriate management practices for germplasm screening; 3) develop crop management strategies to optimize productivity in different agro-ecological systems.

Results from residue management experiments conducted at El Batan (K. Sayre, unpublished data) indicate wheat and maize yields can be significantly improved through zero tillage and stubble retention practices (Figure 4). Significant advances have been made in water and nitrogen management in the Yaqui Valley in northwestern Mexico through the introduction of bed planting (Sayre, 1998). The technology is now being evaluated in India, Pakistan, Iran and China with the aim of increasing farmer returns per hectare.

(4) Develop and use data bases, such as the International Wheat Information System (IWIS), to improve the adaptation of wheat to abiotic stress

Improved collection/use of information and characterization of testing environments:

The CIMMYT wheat program distributes wheat germplasm around the world each year. Cooperators from many countries return yield and disease information collected on these germplasm sets. The information on the performance of key lines in low yielding environments is used to drive the crossing program at base in Mexico. Environments are characterized on the basis of their stress patterns and crosses are made among the various specific and general performers. The aim of this strategy is to combine those parts of the genome contributing to drought tolerance in different stress environments. Whilst most cooperators will return yield data, there is scant information returned on environmental parameters or other potentially confounding stresses, such as disease and micro-nutrient imbalances. The mechanism contributing to the superior performance of a particular genotype in one environment cannot be properly understood. It is therefore critical that the global testing environments are properly characterized year to year. The same principle applies to multi-location yield evaluation networks within smaller regional wheat improvement programs.

Data management systems such as IWIS are of fundamental importance if breeders and associated researchers are to fully utilize these international data. IWIS is currently undergoing modification to encompass a wider range of cultivated cereals. This new system, now known as the International Crop Information System (ICIS), will provide both pedigree and data management options to breeders and genetic resource managers working in different crop species.

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Questions and Answers:

Izzat S.A. Tahir: One of the constraints of wheat production under marginal areas is the cost of production relative to yield per unit area, also the quality of wheat produced (especially under heat stress), so what will be CIMMYT's approach to address such production constraints?

Answer: Concerted approach: increase in yield via incorporation of stress-adaptive traits and enhanced N use efficiency while decreasing cost of production via modern crop management research technologies (co-development). Effect on production *per se* and improved end-use quality.

M.A. Mahir: Try to fulfil the great goals of GP5 via simple biotechnology - for example: the Japanese are experimenting on the possibility of developing a kind of symbiotic relationship between a rhizobium strain and wheat.

Answer: We have colleagues from biotechnology in the GP5 team. They are involved in the development of molecular markers for stress-adaptive traits and to monitor other traits

available which could be used. Biotechnological tools have great potential and are an integral part of GP5 research activities.

Figure 1. Yield performance of bread wheat derived from crosses with Synthetic and Durum wheat parents under drought (Yaqui Valley 1998-99).

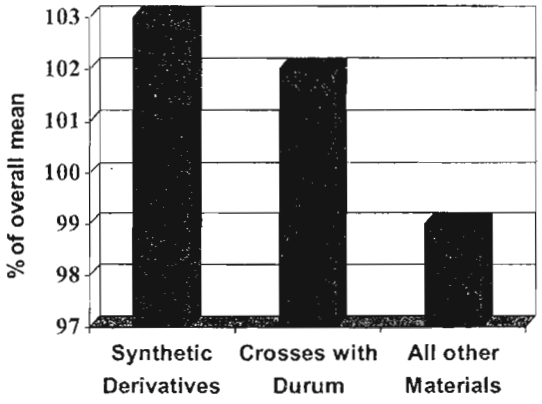


Table 1. Characterization of the GP5 target abiotic stress environments.

Moisture stress scenarios	Temperature extremes	Nutrient stress - macro/micro and pH extremes
• Terminal • Pre-Anthesis • Residual Moisture • Reduced Irrigation • General Low Rainfall • Shallow, Marginal, Infertile, Eroded Soils	• Heat Stress Humid • Heat Stress Dry • Cold Stress • Cold Stress – Late Frost	• P and N Deficiency/ Efficiency • Deficiency (e.g. Zinc) • Toxicity (e.g. Boron) • Acid Soils Mineral • Acid Soils Volcanic/Organic • Alkaline Soils

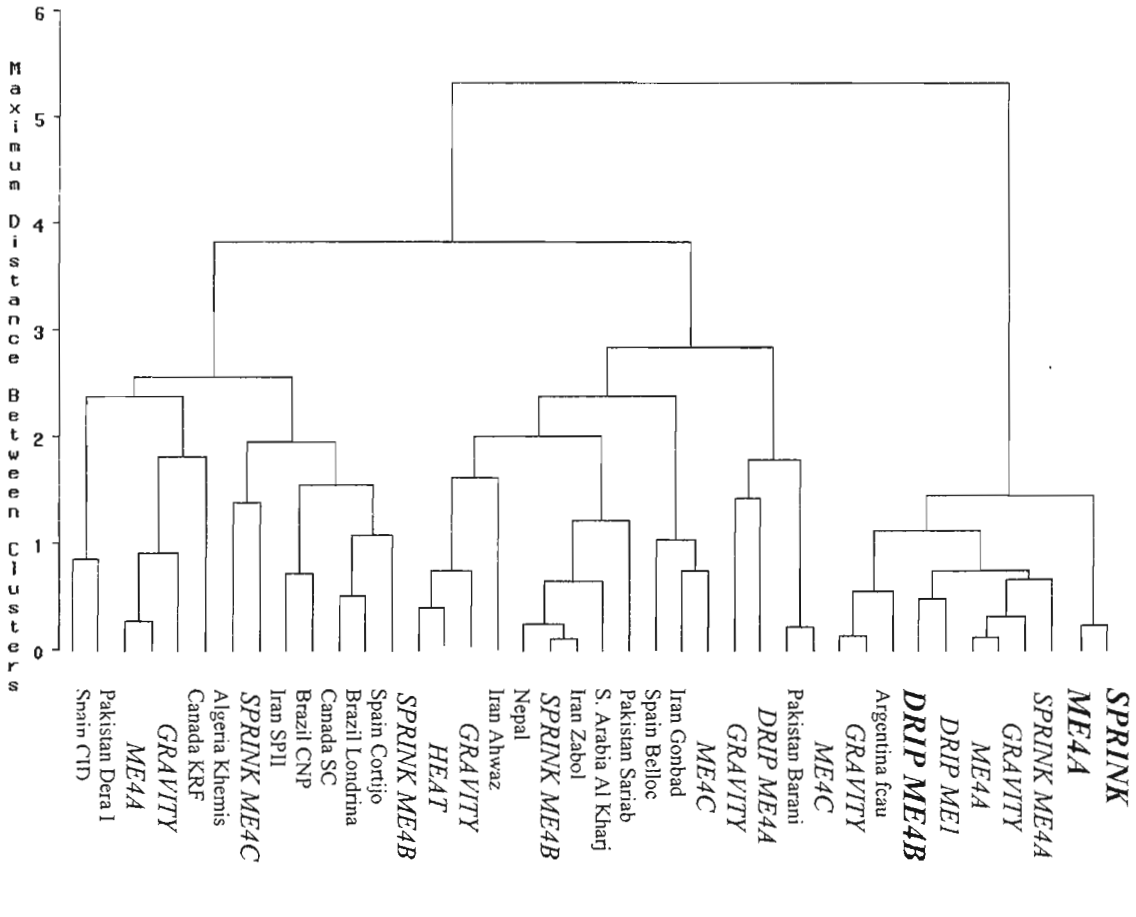


Figure 2. Dendogram of SAWYT test sites clustered against drought simulated environments at Cd. Obregon, Sonora, Mexico in 1998-99 and 1999-00.

Figure 3. Genetic Progress in Phosphorus Efficiency in Bread Wheat

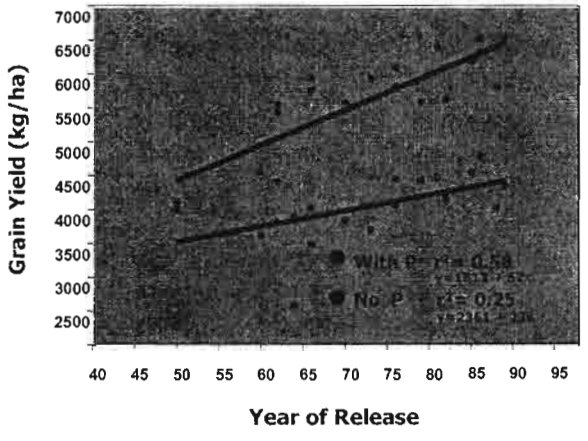
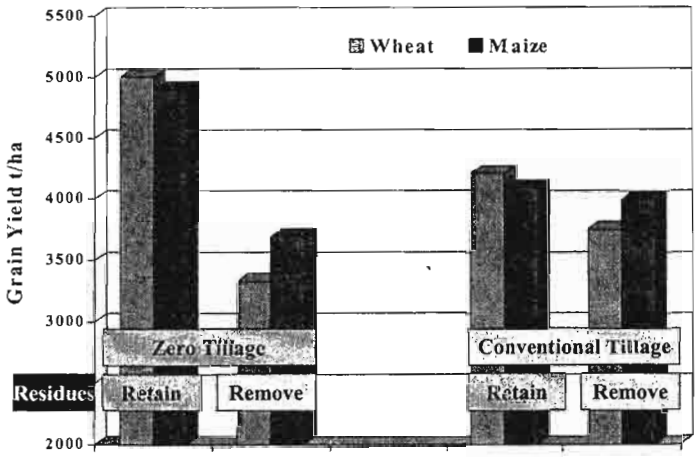


Figure 4. Effect of crop residue management and tillage on maize and wheat yields under rainfed conditions (El Batan, average 1996-1998).



SOURCES OF VARIATION FOR GRAIN YIELD PERFORMANCE OF BREAD WHEAT IN NORTHWESTERN ETHIOPIA

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ABSTRACT

Precise genotypic yield estimates from data of regional variety trials will increase the probability of successful selection. Additive main effects and multiplicative interaction (AMMI) analysis helps to understand sources of variation, to interpret the genotype by environment (GE) interaction, and to improve the probability of successful selection. A regional variety trial conducted in 12 environments was subjected to AMMI analysis to reveal the sources of grain yield variations and interaction. Environment and genotypes were highly significant but their interaction was non-significant. The environment sum of squares (SS) dominated the analysis even though the interaction SS was larger than genotypic SS. AMMI partitioned the interaction SS into six Interaction Principal Component Axes (IPCAs) with two of them significant; the AMMI biplot described different patterns of interactions. The contribution of environment was 86.4%, indicating differences in environments (i.e., genotype yields ranged from 6205 kg/ha at Adet to 1643 kg/ha at Injibara, as Injibara is the lowest potential area for wheat production). Genotypes contributed 5.7% of the variation and the difference between them was significant. Genotypes such as HAR1868, HAR1865 and HAR2096 were consistently high yielding varieties across environments with mean yields of 4105, 3932 and 3786 kg/ha, respectively. They had positive interaction with high yielding locations (Adet, Motta, Fenoteselam and Dabat) indicating their adaptation to these locations. The above locations showed consistency of main effects and interactions across years (i.e., the environments were suitable to discriminate this set of genotypes). Therefore, the result indicated consistency of ranking of genotypes (i.e., the top yielding in the top four ranks in both AMMI predicted and observed yields) that facilitates the use of mean yields as a selection criterion for variety recommendations. As a result, HAR1868 (Shina) was recommended for production in 1998 and HAR2096 was verified for release in 1999.

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is a major crop in Northwestern Ethiopia. Farmers demand to grow high yielding semi-dwarf bread wheat cultivars, because of better grain yield potential than many traditional crops. Wheat grows in a wide range of areas in the region differing in altitude, soil type, temperature, rain fall distribution, and the grain yield potential

varies from place to place. Multi-environmental trials play important role in selecting the best cultivars (or agronomic practices) for different locations and in assessing a cultivar's stability across environments before it's commercial release (Mateo *et al.*, 1999). Grain yield is the major criterion for selection in multi-environment testing. Cultivars react differently to environmental changes and differential responses of cultivars vary from one environment to another i.e., genotype by environment (GE) interaction. The potential of a genotype to be stable under different environments is important and understanding of the interaction is vital for selecting superior genotypes.

GE interaction can be a result of genotype rank changes from one environment to another, difference in scale among environments, or a combination of both (Cornelius *et al.*, 1993). The occurrence or absence of GE interaction in multi-environment testing of genotypes is important in a plant breeding program. In GE interaction, it is worthwhile distinguishing between interaction due to heterogeneity of genotypic variances among environments and the lack of correlations of genotypic performance among environments, the latter results in re-ranking of genotypes across environments (Cooper and DeLacy, 1994). Yield data observed during multi-location trials can be divided into pattern and noise (Freeman, 1973). The observed mean should not be taken as a true mean because of error and noise in the data and therefore it is important to adjust (Gauch and Zobel, 1988; Zobel *et al.*, 1988) past yields to predict and improve future yields.

The options to improve predictive accuracy of a yield trial include improved experimental techniques, improved experimental design (more replications or sophisticated layouts of the replications) or more efficient statistical analysis. Many models have been developed to describe GE interaction and the additive main effects and multiplicative interaction (AMMI) model is a widely used statistical analysis of yield trial data. AMMI gives adjusted means, which have better predictive accuracy and hence greater value for making selection than unadjusted (observed) means (Gauch and Zobel, 1989). The total sum of squares (SS) for grain yield data can be partitioned into several sources: the genotype main effect, the environment main effect, and the genotype by environment interaction. By definition, main effects are additive and interactions (residual from the additive model) are non-additive, and all the three sources are important (Zobel *et al.*, 1988). AMMI uses the usual analysis of variance (ANOVA) to compute genotype and environmental additive effects and applies principal component analysis (PCA) to analyze non-additive interaction effects. Furthermore, the biplot of AMMI displays both main effects (genotype and environment means) and interactions (IPCAs) for interpretation of these relationships. Changes in Y-axis and X-axis on the biplot shows changes in interaction and main effects, respectively. This paper uses AMMI to analyze the multi-location yield trial conducted in 1997 and 1998 in Northwestern Ethiopia and examines the GE interaction and identify sources for grain yield variation.

MATERIALS AND METHODS

A regional variety yield trial was conducted in 1997 and 1998 in Northwestern Ethiopia. The trial was a full factorial consisting of 20 varieties along with the standard and local checks in 12 environments (two years at six locations). Year by site combinations were taken as an environment. The design was a randomized complete block in four replications with a plot size of 3 m^2, i.e., 6 rows at 20 cm spacing and 2.5 m length. Seed rate of 150 kg ha^{-1} and fertilizer rate of 92/46 kg N/P_2O_5 ha^{-1} were used. All other growing practices were as recommended for all sites. The locations were Adet, Motta, Debre Tabor, Dabat, Fenote Selam and Injibara, Ethiopia separated between 75 to 300 km from the breeding center, Adet,

and ranging from 1900 to 2650 m a.s.l. The soil was drained at all sites. The data was balanced, i.e., experiments at all environments had 20 varieties and four replications. Grain yield was expressed in kg ha^{-1} at 12.5% moisture. AMMI analysis was performed using Agrobase software (1998). The significance of the grain yield data was tested using the F-test. The observed and AMMI predicted grain yields were considered for interpretation. The genotype by environment interaction was illustrated by means of biplot, i.e., genotype and site mean on the X-axis and interaction principal components of the genotypes and sites on Y-axis.

RESULTS AND DISCUSSION

The ANOVA suggested environmental diversity and varietal variability in grain yield. The observed mean grain yield performance of varieties across environments ranged from 2895 to 4105 kg ha^{-1} (Table 1). The highest mean yielding variety was HAR1868 followed by HAR1685 (the standard check) and HAR2096. The highest yielding site was Adet (4752 kg ha^{-1}) and the least Injibara (2760 kg ha^{-1}). The top ranking varieties produced higher yields than the overall mean yield at most environments. The AMMI analysis of variance indicated that additive effects of environments and genotypes were significant, but their interaction was not significant (Table 2). The environment sum of squares (SS) dominated the analysis even though the interaction SS was larger than genotype SS. However, the interaction was more important and AMMI partitioned the interaction SS into six IPCAs (interaction principal component analysis) and the F-test indicated that AMMI2 (IPCA1 and IPCA2) explained the GE interaction. Both IPCAs captured 56 % of the interaction SS and 28 % interaction degrees of freedom (d.f.). The large residual d.f. of 153 contained non-significant IPCAs. The contribution of each of the sources of variation is presented in Table 3. The contribution of environment (86.4%) was high for yield variation which indicated differences among the environments.

The AMMI1 biplot provided further interpretation of the results with different patterns of interaction displaying both genotype and environment main effects (mean yields) and interaction (Fig. 1). The genotype and environment means are shown on the abscissa and interaction PCA values on the ordinate representing both main effects and interactions. The biplot captured the genotype SS, environment SS and IPCA1 SS of the interaction. The biplot revealed 94.4 % of the treatment SS (Treatment = genotype + environment) explaining the interaction leaving 5.6 % to the residual SS where in most trials the first IPCA is selected as most predictive. Therefore, most of the treatment SS were explained by the biplot leaving 5.6% of the residual SS as noise with no interpretable value.

Genotypes and environments having the same sign on the IPCA axis have positive interaction and negative interaction with the opposite sign. The IPCA scores of a genotype in the AMMI analysis are an indication of the stability of a genotype over environments. The greater the IPCA scores, either negative or positive, as it is a relative value, the more specifically adapted a genotype is to a certain environment. The more the IPCA score is approximate to zero, the more stable the genotype is over the sampled environments (Purchase, 1997). Environments showed variability in main effects (mean yields) and interaction (IPCA). Four of the six environments (Adet, Fenote Selam, Dabat and Motta) in 1997 had above average yield response and had negative interactions. In 1998, some of the environments performed poorly and gave below average grain yield and had positive interaction indicating the variability between years and/or environments. However, the highest yielding environment (Adet in 1997 and 1998) had consistent main effect and repeated interactions. It also had positive

interaction with the highest yielding varieties. Other high yielding sites like Motta, Fenote Selam and Dabat also interacted well with high yielding varieties even though Dabat and Motta were variable for either interaction and/or main effects in both years. The lowest yielding sites, Debre Tabor and Injibara had consistent interaction and main effects. However, the presence of grain yield variation in testing environments did not cause significant GE interaction.

Many of the genotypes had a similar main effect but with varying negative and positive interaction (Fig. 1). Genotypes 2, 5, 6, 9 and 20 had positive interaction with genotype 20 having the highest positive IPCA score. Genotypes 3, 12, and 18 had interactions close to zero indicating their stability of performance. Above average mean yield performance was scored by genotypes HAR 1868, HAR 2096 and HAR 1685 in both years and they showed similar interaction with most environments in 1997 and a few in 1998. All three genotypes were consistently top ranking across environments and achieved good yields in high yielding sites. The AMMI predicted (adjusted) yield and observed mean had little variation in ranking of varieties where most high yielding varieties fall with in the top four rankings (Table 1). AMMI selected HAR 1868 as first in eight environments, HAR 1865 as first and second in seven environments and HAR 2096 as third in overall mean performance. The same varieties were ranked similarly by the observed means. HAR 1868 maintained its ranking both seasons which indicated the level of GE interaction was low to the responses of the varieties where the top yielding varieties maintained their superiority across environments under the selected regional testing sites. As a result, HAR 1868, higher yielding than the standard check (HAR 1685), was released in 1998 and HAR2096 was verified for release in 1999.

CONCLUSIONS

Adet, Fenote Selam, Debre Tabor and Injibara showed consistency in both main effects and interactions and are suitable environments for selecting for wider adaptability. Injibara had the highest positive interaction and lowest yield performance indicating the area had the lowest potential for wheat production. Motta showed differences in main effects in both years with little change in interaction. The most variable site for interaction was Dabat but with little change in relative ranking of genotypes in both years. Regardless of the yield levels, the testing environments/sites may be considered effective for selection since most of them discriminate or rank the varieties similarly, i.e., environments had low or insignificant GE interaction. Therefore, low level of GE interaction and the consistency of ranking of varieties will give an opportunity to exploit the mean yields of varieties as a recommendation criterion or the best estimate for yield of a genotype is the treatment mean. As a result, the top mean yielding variety (HAR 1868) had positive interaction with most of the environments and was verified and approved for release in 1998. The other high yielding variety, HAR 2096, was verified for release in the 1999 cropping season. These varieties are semi-dwarf which showed great potential for grain yield. The breeding program must focus on developing widely adapted, high yielding semi-dwarf wheats to increase its efficiency by targeting to potential areas for higher production and productivity. Furthermore, confirmation of repeatability of low GE interaction with different sets of genotypes and more environments in the region helps to evaluate, select and make reliable recommendations in the region.

ACKNOWLEDGMENTS

The wheat breeding program at Adet annually receives germplasm either as introductions, or bred and advanced by the national program. These materials are subjected to regional

environments for releasing a variety for the region. The Adet wheat program is delighted to thank the national breeding program for the provision of advanced materials for such use. Also, we would like to acknowledge the technical and material assistance of CIMMYT/CIDA EACP and CIMMYT/EU Breeding/Pathology programs.

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Table 1. Grain yield (kg ha^{-1}) observed (OM) and AMMI predicted (AMMIZ) of 20 wheat varieties tested at 12 environments in north-western Ethiopia.

#	Genotype		Environment												Mean	IPCA2
			AD97	AD98	FS97	FS98	MO97	MO98	DA97	DA98	DT97	DT98	IN97	IN98		
1	HAR1868	*AMMI2*	5019(1)	6205(1)	4799(1)	3725(1)	5750(1)	2781(3)	5028(1)	3076(4)	2869(1)	3674(4)	3988(1)	2344(5)	4105(1)	-6.5
		OM	4845(1)	6094(2)	4758(1)	3774(1)	5737(3)	2908(4)	5406(1)	2876(5)	2917(2)	3921(4)	3970(1)	2053(14)		
2	HAR1918	*AMMI2*	3936(12)	5663(5)	4109(10)	3352(4)	5712(2)	2106(20)	4218(18)	2574(16)	2557(8)	4094(1)	3576(8)	2556(2)	3705(7)	-22.7
		OM	4091(10)	5569(11)	4154(9)	3623(2)	5351(8)	1564(20)	4154(16)	2759(12)	2840(3)	4034(2)	3604(6)	2722(1)		
3	HAR2096	*AMMI2*	4332(6)	5756(4)	4322(6	3384(3)	5331(3)	2426(7)	4548(6)	2805(9)	2638(6)	3683(3)	3668(3)	2345(4)	3786(3)	-10.3
		OM	4089(11)	6155(1)	4324(5)	3520(3)	5317(9)	3092(1)	4204(14)	2798(8)	2271(16)	4018(3)	3686(3)	1964(15)		
4	HAR2103	*AMMI2*	3856(15)	5506(11)	4078(12)	3266(6)	5505(4)	2396(8)	4345(11)	2863(7)	2695(4)	3894(2)	3603(5)	2616(1)	3719(5)	-11.1
		OM	3784(15)	5580(8)	3918(17)	3244(8)	5502(4)	2653(7)	4391(10)	2816(6)	2719(6)	4163(1)	3593(7)	2260(6)		
5	HAR 1875	*AMMI2*	3848(16)	5232(14)	3868(15)	2901(15)	4982(14)	2151(18)	4182(19)	2531(18)	2280(18)	3140(14)	3248(15)	1914(13)	3359(15)	-3.9
		OM	3682(18)	5473(13)	4229(6)	2629(17)	5066(12)	1961(17)	4085(17)	2776(11)	2130(20)	2968(13)	3267(15)	2076(12)		
6	HAR1781	*AMMI2*	3756(18)	5256(13)	3909(13)	3006(13)	5124(11)	2349(10)	4265(15)	2778(10)	2509(9)	3411(5)	3395(13)	2278(6)	3503(14)	-2.9
		OM	3699(17)	5175(16)	4083(10)	2689(16)	5357(7)	2415(10)	4381(11)	2753(13)	2435(10)	3438(6)	3378(14)	2235(7)		
7	HAR2025	*AMMI2*	4143(10)	5529(10)	4082(11)	3124(10)	5263(8)	2111(19)	4285(13)	2474(20)	2321(14)	3366(7)	3386(14)	1992(11)	3506(13)	-11.3
		OM	3992(12)	5741(4)	4080(11)	3302(6)	5285(11)	1896(19)	4192(15)	2690(16)	2321(14)	3121(9)	3398(13)	2056(13)		
8	HAR2524	*AMMI2*	4670(4)	5852(2)	4420(4)	3349(5)	5389(5)	2331(13)	4620(5)	2620(15)	2440(11)	3293(9)	3588(6)	1914(15)	3707(6)	-8.5
		OM	4843(2)	5577(10)	3933(16)	3151(11)	5940(1)	2631(8)	5138(3)	2191(20)	2264(17)	3112(11)	3543(8)	2166(18)		
9	HAR2530	*AMMI2*	3651(19)	5143(16)	3901(14)	2984(14)	5025(13)	2662(5)	4400(9)	3111(3)	2716(3)	3379(6)	3480(9)	2466(3)	3576(10)	6.6
		OM	3552(19)	5438(12)	3946(15)	2585(18)	4841(13)	2927(3)	4558(7)	3040(3)	2465(8)	3724(5)	3481(9)	2360(3)		
10	HAR2534	*AMMI2*	3967(11)	5146(15)	3863(16)	2774(18)	4710(17)	2221(16)	4258(16)	2541(17)	2188(20)	2712(18)	3162(18)	1643(20)	3265(18)	4.6
		OM	3878(14)	5339(14)	3846(18)	2584(19)	4600(16)	1952(18)	4415(9)	2663(17)	2447(9)	2817(17)	3158(18)	1484(20)		
11	HAR2536	*AMMI2*	3894(13)	5100(18)	3852(18)	2776(17)	4698(18)	2344(11)	4300(12)	2683(12)	2288(17)	2753(16)	3206(17)	1766(17)	3305(17)	7.6
		OM	3990(13)	4838(18)	4061(12)	2775(15)	4451(17)	2226(15)	4374(12)	2810(7)	2228(18)	3118(10)	3191(16)	1598(18)		
12	HAR2165	*AMMI2*	3881(14)	5131(17)	3856(17)	2806(16)	4767(16)	2301(15)	4273(14)	2651(14)	2290(16)	2849(15)	3218(16)	1812(16)	3320(16)	4.9
		OM	4169(9)	4705(19)	4212(7)	3303(5)	4339(19)	2340(11)	3715(20)	2796(9)	2175(19)	3073(12)	3189(17)	1819(16)		
13	HAR2195	*AMMI2*	4181(9)	5450(12)	4135(9)	3099(12)	5096(12)	2470(6)	4499(7)	2817(8)	2505(10)	3169(12)	3472(10)	2050(10)	3579(9)	1.2
		OM	4556(5)	5578(9)	3965(14)	2818(14)	4794(14)	2258(12)	4425(8)	2725(14)	2733(5)	3182(7)	3473(11)	2407(2)		
14	HAR2258	*AMMI2*	4313(8)	5542(9)	4190(7)	3134(9)	5140(10)	2376(9)	4498(8)	2700(11)	2430(12)	3145(13)	3462(11)	1940(14)	3573(11)	-1.9
		OM	4180(8)	5211(15)	4551(2)	3232(9)	5428(5)	2241(13)	4629(5)	2668(16)	2302(15)	2859(15)	3439(12)	2130(9)		
15	Dashen	*AMMI2*	4405(5)	5597(7)	4323(5)	3240(7)	5176(9)	2718(4)	4732(4)	3046(5)	2683(5)	3197(10)	3640(4)	2149(9)	3742(4)	5.3
	(bucxpun)	*OM*	4421(7)	5585(7)	4165(8)	3382(4)	5386(6)	2700(6)	4563(6)	3004(4)	2993(1)	2956(14)	3644(4)	2109(11)		
16	HAR2018	*AMMI2*	4780(2)	5569(8)	4441(3)	3119(11)	4779(15)	2940(2)	4990(3)	3147(2)	2599(7)	2484(20)	3585(7)	1663(19)	3675(8)	20.7
		OM	4695(4)	5918(3)	4368(4)	3281(7)	4627(20)	2755(5)	4962(4)	3416(1)	2553(7)	2752(18)	3628(5)	1504(19)		

Table 1. Continued.

17	HAR2527	*AMMI2*	4314(7)	5622(6)	4185(8)	3182(8)	5281(6)	2180(17)	4391(10)	2515(19)	2347(13)	3310(8)	3440(12)	1942(12)	3559(12)	-9.9
		OM	4518(6)	5626(6)	4002(13)	3166(10)	5306(10)	2092(16)	4268(13)	2548(18)	2406(11)	3170(8)	3476(10)	2129(10)		
18	HAR1709	*AMMI2*	3777(17)	4981(19)	3775(19)	2675(19)	4582(19)	2313(14)	4232(17)	2657(13)	2235(19)	2650(19)	3128(19)	1709(18)	3224(19)	9.6
	(st.ch1)	*OM*	3719(16)	4971(17)	3826(19)	3002(13)	4646(15)	2616(9)	3830(19)	2412(19)	2396(12)	2410(20)	3121(19)	1745(17)		
19	HAR1685	*AMMI2*	4749(3)	5815(3)	4578(2)	3421(2)	5276(7)	2978(1)	5018(2)	3266(1)	2855(2)	3193(11)	3832(2)	2197(7)	3932(2)	9.3
	(st.ch2)	*OM*	4739(3)	5704(5)	4546(3)	3088(12)	5898(2)	3011(2)	5138(2)	3209(2)	2815(4)	2844(16)	3838(2)	2349(4)		
20	ET-13A2	*AMMI2*	2448(20)	4078(20)	2988(20)	2135(20)	4128(20)	2342(12)	3715(20)	2878(6)	2306(15)	2731(17)	2817(20)	2172(8)	2895(20)	19.4
	(L. check)	*OM*	2479(20)	3932(20)	2991(20)	2304(20)	4404(18)	2229(14)	3971(18)	2783(10)	2338(13)	2448(19)	2819(20)	2340(5)		
	Mean		4096	5409	4083	3073	5096	2425	4440	2787	2487	3206	3445	2075		
	IPCA2		-1.3	-11.5	-0.9	-7.6	-19.3	22.8	11.8	21.3	8.5	-22.8	1.1	-2.4		

AMMI2 = AMMI2 predicted mean yield; OM = observed mean yield; ( ) = numbers in parenthesis are ranks; IPCA2 = interaction principal component axis 2; Environments are indicated by location codes followed by year. E.g. AD97 = location Adet in 1997; DT = Debre Tabor; FS = Fenote Selam; DA = Dabat; MO = Motta; IN = Injibara.

Table 2. AMMI2 analysis of variance for grain yield.

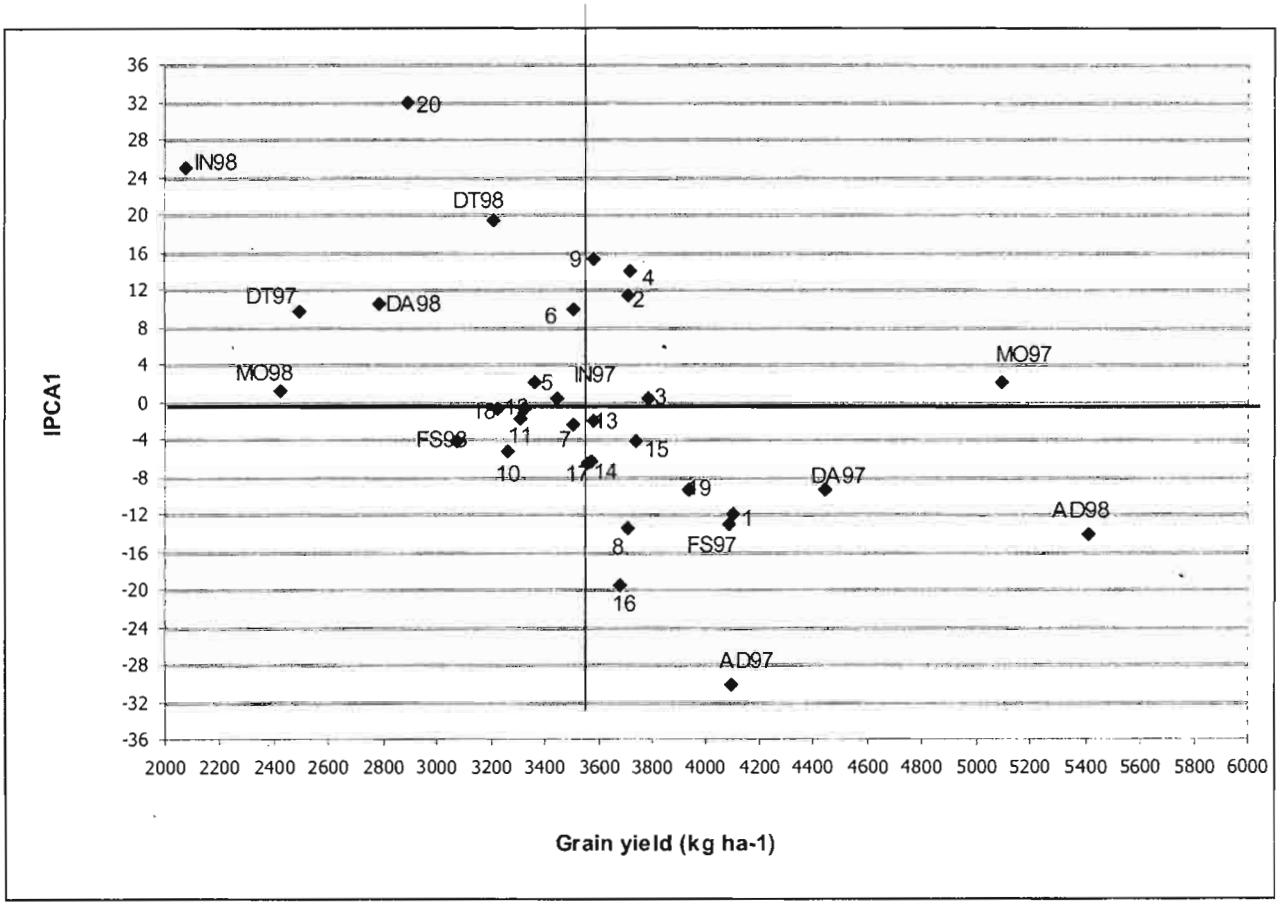
Source	d.f.	Sum of Squares	Mean Square	F-value
Total	959	1509825707.5		
Environments	11	1018222644.2	92565694.9	75.27***
Rep within environments	36	44269979.7	1229721.7	
Genotype	19	67755892.9	3566099.6	8.03***
Genotype x environment	209	92787046.3	443957.2	1.06 NS
IPCA1	29	27355096.0	943279.2	2.25***
IPCA2	27	20639342.8	764420.1	1.82***
IPCA residual	153	44792607.5	292762.1	
Residual	684	286790144.4	419283.8	

NS = non-significant; *** = significant at P 0.001.

Table 3. Contribution of each source for grain yield variation.

Sources of variation	Contribution (%)
Environment	86.5
Genotype	5.7
Environment by genotype	7.8

Figure 1. AMMI biplot of means (kg ha^{-1}) and IPCA score for 20 genotypes and 12 environments.



Numbers 1-20 represent varieties; Environments = letters are location codes followed by years.

GERMPLASM ENHANCEMENT THROUGH WIDE HYBRIDIZATION AND MOLECULAR BREEDING

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ABSTRACT

Wild relatives of wheat are a rich source of novel variability for disease resistance, quality and other traits of economic importance. Evaluation and cataloguing of 1,000 accessions of wild *Triticum* and *Aegilops* species identified a number of new sources of resistance to leaf rust, stripe rust, powdery mildew, loose smut, leaf spots and cereal cyst nematode. Study of high molecular weight (HMW) glutenin subunit composition by SDS-PAGE revealed large intra-specific diversity in the wild species and identified novel Ax and Ay subunits at the *Glu A1* locus. Interspecific crossing of resistant accessions of three wild *Triticum* species with susceptible *Triticum durum* (AABB) lines, followed by back-crossing to the cultivated species, resulted in the transfer of: leaf rust resistance from six diverse accessions of *T. araraticum* (AAGG); stripe rust resistance from one accession of *T. urartu* (A^uA^u), two accessions of *T. araraticum* and one accession of *T. dicoccoides* (AABB); and powdery mildew resistance from two accessions of *T. araraticum*. Transfer of novel Ax and Ay subunits from *T. urartu*, *T. boeoticum* (A^bA^b), *T. dicoccoides* and *T. araraticum* resulted in significant increase in gluten strength indicated by increases in SDS sedimentation value from 37-40 for *T. durum* to 48-75 for the derivatives. Non-progenitor *Aegilops* species with C, U and M genomes have been found to be excellent sources of resistance to leaf rust and stripe rust. Rust resistant interspecific derivatives carrying alien chromosome substitution/addition or translations from *Ae. ovata* (UUMM) and *Ae. triuncialis* (UUCC) have been identified using C-banding and genomic *in-situ* hybridization techniques. Studies showed that the inhibitor of the *Ph* locus (Ph^I) from *Aegilops speltoides,* now available in the background of *T. aestivum* cv. Chinese Spring, is useful to induce homoeologous pairing of alien chromosomes with wheat chromosomes in interspecific crosses. Induced homologous pairing coupled with C-banding and genomic *in-situ* hybridization are useful to transfer small alien segments carrying desirable genes and thus reduce linkage drag. A molecular linkage map has been constructed for the diploid cultivated species *T. monococcum* – a good source of resistance to diseases and pests and possessing resistance to herbicides. Molecular markers linked to protein content and seed size have also been identified. Also, in a pre-breeding program to improve two spring wheat cultivars, novel genes for disease resistance, high protein content, bread making quality and other agronomically important traits have been transferred from various genetic stocks. The improved durum and bread wheat materials, particularly those with rust resistance and processing quality, seem to have great potential for deployment in East Africa including Ethiopia.

INTRODUCTION

Wild relatives of wheat provide a rich reservoir of genes for desirable traits (Sharma and Gill, 1983; Jiang *et al.,* 1994; Friebe *et al.,* 1994). A number of genes for disease resistance, quality and other traits of economic importance have been transferred from both close as well as distantly related species. Evaluation of different accessions of wild *Triticum* and *Aegilops* species (1000 accessions), both under natural and artificial conditions at the Punjab Agricultural University, identified a number of new sources of resistance to leaf rust, stripe rust, powdery mildew, loose smut, Karnal bunt, leaf spots and cereal cyst nematode. (Dhaliwal *et al.*, 1993; Pannu *et al.*, 1994; Dhaliwal and Harjit-Singh, 1997; Harjit-Singh *et al.*, 1998). It was found that *Ae. speltoides* (S) and *T. boeoticum* (A^b) are good sources of resistance to leaf rust (*Puccinia recondita* f.sp. *tritici*) and stripe rust *(Puccinia striiformis).* Among relatively less closely related species, diploid *Aegilops* species with C, U and M genomes and polyploid species carrying combinations of these genomes are excellent sources of resistance to these two rusts (Dhaliwal *et al.*, 1991, 1993; Harjit-Singh and Dhaliwal, 2000). Cataloguing of variability for resistance to leaf rust and stripe rust among accessions of wild *Triticum* and *Aegilops* species with individual isolates of rust revealed a large intraspecific diversity within these species (Harjit-Singh and Dhaliwal, 2000). The study identified 45 accessions, majority of which belonged to *Ae. speltoides* (S), *T. boeoticum* (A^b) and *Ae. triuncialis* (UC), that maintained their resistance to the two rusts over years (1984 to 1998) and locations, thereby further supporting usefulness of these species as the sources of rust resistance (Harjit-Singh *et al.,* 1998) .The screening of germplasm for resistance to powdery mildew (*Erysiphe graminis* f.sp. *tritici*) under natural epiphytotic conditions and in the laboratory conditions, by inoculation of seedling and detached leaves using two isolates of known virulence, identified 25 sources of resistance among two wild *Triticum (T. araraticum and T. boeoticum*) and two *Aegilop*s (*Ae. speltoides* and *Ae. squarrosa*) species (Gill *et al.*, 1995). Evaluation of wild *Triticum* and *Aegilops* species for loose smut resistance under artificial conditions indicated that *T. boeoticum*, *T. dicoccoides*, *T. araraticum* and *Ae. cylindrica* are good sources of resistance (Grewal *et al.*, 1997). Screening of four wild *Triticum* and 14 *Aegilops* species for resistance to Punjab population of cereal cyst nematode, *Heterodera avenae*, under artificial conditions, suggested that *Aegilops* species with C and U genome are good sources of resistance to this pest (Singh *et al.*, 1991; Gill *et al.*, 1995). Also, a large variability for High molecular weight (HMW) glutenin submit composition, a character associated with bread making quality, has been observed in wild *Triticum* and *Aegilops* species (Randhawa *et al.*, 1995, 1997). Keeping this in view a program was initiated to transfer genes for disease resistance and novel HMW glutenin subunits from the alien identified sources.

Nine wild species (Table1) were used as donors for transfer of desirable traits which included leaf rust, powdery mildew, Karnal bunt and cereal cyst nematode resistance, and novel HMW glutenin subunits. Susceptible *T. durum* lines were used as recipient cultivated parent to transfer leaf rust, stripe rust and powdery mildew resistance from wild *Triticum* species. An agronomically superior but susceptible bread wheat cultivar, WL 711, was crossed to one resistant accession each of *Ae. ovata* (UM) and *Ae. triuncialis* (UC) to transfer leaf rust, stripe rust, powdery mildew, Karnal bunt and cereal cyst nematode resistance by backcross method (Harjit Singh *et al.,* 1993). To transfer disease resistance genes from two non progenitor diploid *Aegilops* species, *Ae. candata* (C) and *Ae. umbellulata* (U), *T. durum* (susceptible) – *Aegilops* species amphiploids were developed. These amphiploids were crossed with susceptible *T. aestivum* to transfer the genes to hexaploid background. Data on chromosome

number and meiotic chromosome pairing was recorded in the F_1 and subsequent backcross and selfed progenies. The addition, substitution or translocation of the alien chromosome(s) or chromosome part(s) were investigated through Giemsa C-banding (Friebe *et al.*, 1992) and genomic *in-situ* hybridization (Mukari and Gill, 1991). A *T. aestivum* cv. Chinese Spring line possessing Ph^1 (*Ph* suppressor) gene from *Ae. speltoides* was crossed with *Secale cereale, Aegilops ventricosa* and amphiploids of *T. durum-Ae caudata* and *T. durum–Ae. umbellulata* to study the usefulness of Ph^1 gene in inducing homoeologous pairing between the chromosomes of the alien and the cultivated species. Amphiploids of *T. durum-squarrosa* were crossed to susceptible *T. aestivum* cv. Veery to transfer leaf rust and Karnal bunt resistance from one accession each of *Ae. squarrosa*. Backcrossing was used to transfer novel HMW glutenin subunits from four wild *Triticum* species into *T. durum* cv. PBW 34.

Successful transfer of desired variability has been achieved in many interspecific crosses (Table 1). In others, the material is in advance generations. Leaf rust resistance has been transferred from six diverse accessions of *T. araraticum* into rust susceptible *T. durum* lines. Fully fertile resistance plants with 14 bivalents were selected in BC_2/BC_2F_2 generation to produce backcross derivatives with the desired resistance. Similarly, stripe rust resistance and powdery mildew resistance has been transferred from two accessions each of *T. araraticum*. Fertile stripe rust resistance derivatives have been developed from the cross of susceptible *T. durum* cv. Bijaga Yellow with *T. dicoccoides* Acc. 4656. Stripe rust resistance has also been transferred from another accession (4637) of *T. dicoccoides into T. aestivum* cv. Hybrid 65. A derivative carrying stripe rust resistance from *T. urartu* in susceptible *T. durum* has also been developed. Leaf rust resistance segregants have been selected from the cross of the susceptible *T. aestivum* parent with *T. durum-Ae. squarrosa* (Acc 3743) amphiploids (Table 1). A similar cross involving *Ae. squarrosa* Acc 3806 is being used to transfer Karnal bunt resistance from this progenitor species.

Alien substitution/addition lines carrying resistance to one or more of leaf rust, stripe rust, powdery mildew, Karnal bunt and/or cereal cyst nematode from *Ae. triuncialis* and *Ae. ovata* in the background of susceptible *T. aestivum* cv. WL711 have been developed. One group of derivatives with 42 chromosomes, spelta-type head and resistance to cereal cyst nematode and powdery mildew in addition to moderate resistance to leaf rust were recovered from crosses with *Ae. triuncialis*. Giemsa C banding of mitotic metaphase chromosomes showed that these derivatives possess a substitution of 5U chromosome of *Ae. triuncialis* for 5A of bread wheat (Harjit-Singh *et al.*, 2000). Another set of interspecific derivatives with disomic addition of an acrocentric *Ae. triuncialis* chromosome possessed leaf rust, Karnal bunt and powdery mildew resistance. Genomic *in-situ* hybridization showed that this set of derivatives also possesses a pair of translocated chromosomes involving break point in the centromere and short arm of *Ae. triuncialis* chromosome (Harjit-Singh *et al.*, 2000). In some of the rust resistant backcross derivatives from *Ae. triuncialis*, no alien chromatin could be detected with C-banding and GISH studies. However, molecular cytogenetic characterization of these derivatives indicated that an alien segment carrying leaf rust resistance gene(s) from *Ae. triuncialis* has been transferred to wheat and a STMS (sequence tagged microsatellite) marker *(gwm* 368) allele on 4BS specific to *Ae. triuncialis* is tightly linked to it (Aghaee-Sarbarzeh, Harjit-Singh and Dhaliwal, unpublished data). Similarly, backcross derivatives carrying one or more of the leaf rust, stripe rust and powdery mildew resistance from *Ae. ovata* have been developed. The C-banding study showed a substitution of 5 M chromosome of *Ae. ovata* for 5D of wheat in a uniformly leaf rust and stripe rust resistant derivative. Study of selected interspecific derivatives with mapped microsatellite markers confirmed the substitution of 5M with 5D (Dhaliwal, Harjit-Singh and Williams, unpublished data). This study also

showed that these derivatives possess at least 3 alien translocations, one each to 1BL, 2AL and 5BS. A translocation involving 5DS of wheat and the substituted chromosome 5M of *Ae. ovata* was also observed and the susceptibility of this derivative indicated that the leaf rust resistance gene(s) are located on 5MS. The study also indicated the presence of rust resistance genes on the alien segment translocated to 5BS.

A *T. aestivum* cv. Chinese Spring line possessing Ph^1 (*Ph* suppressor) gene from *Ae. speltoides* was crossed with *Secale cereale* (R) and *Aegilops ventricosa* (DU) to determine the extent of homoeologous pairing induced by the Ph^1 gene so that small segments carrying useful genes on the alien chromosomes (particularly from the less related species like C, U and M genome species) could be transferred to the chromosomes of the cultivated species through genetic recombination. An increase in homoeologous paring between the chromosomes of the alien and the cultivated species in the two crosses (Aghaee-Sarbarzeh *et al.,* 2000) was observed. The same was true in crosses of the *T. aestivum* line carrying Ph^1 with the amphiploids *of Ae. caudata* as well as *Ae. umbellulata*. This suggested that the Ph^1 gene from *Ae. speltoides* is useful to transfer small alien segments through genetic recombination. The availability of this system in *T. aestivum* would allow the exploitation of this system for reducing the linkage drag during the transfer of alien genes.

Most of the *T. durum* lines do not possess HMW glutenin subunits at the *GluA1* locus whereas *T. aestivum* lines have a null allele or alleles expressing only x subunit. Fertile backcross progenies carrying both Ax and Ay subunits from *T. urartu* (A^u), *T. boeoticum* (A^b), *T. dicoccoides* (AB) and *T. araraticum (*AG) have been obtained. Sodium dodecyl sulphate (SDS) sedimentation test has demonstrated the superiority of *T. durum* derivatives carrying the novel HMW glutenin subunits (Table 2). The derivatives carrying both Ax and Ay subunits from the progenitor wild *Triticum* species had SDS sedimentation value of 54.0 to 75.0 against 38.0 of *T. durum* parent. Though the interspecific derivatives possessing only Ax sub unit from the wild parent had lower SDS sedimentation value than those possessing both Ax and Ay subunits, the increase in sedimentation value over the cultivated recurrent parent was still significant. Transfer of novel HMW glutenin subunits from the progenitor species may make the *T. durum* suitable for bread making and also provide new variability for improving bread making quality of *T. aestivum*.

COMMERCIAL UTILIZATION OF ALIEN VARIABILITY

Although wild relatives of wheat provide a rich reservoir of genes for resistance and a number of genes for resistance have been transferred from both close as well as distantly related species, a number of transferred genes have yet not been used in commercial cultivars. It is, because, the majority of translocations involve the substitution of a segment of alien chromatin for a terminal segment of wheat chromatin (Friebe *et al.,* 1996). Deleterious effects may arise either because of the loss of desirable wheat genes or more probably, from the effects of deleterious genes linked to the desirable alien gene. Induction of homoeologous pairing and molecular tagging of the desirable alien genes is helpful in reducing the linkage drag by retaining the desirable derivatives with closely linked markers (Dundas and Shepherd, 1996). Since smaller the alien segment lower the chances of transfer of associated deleterious genes, the monitoring of alien segment through *in-situ* hybridization (using species specific probes) and selection of segregants with smaller alien segment (Castilho *et al.*, 1996) shall be useful in this regard. Therefore, disease resistant addition/substitution lines of *Ae. ovata* (UM) and *Ae. triuncialis* (UC) in the background of *T. aestivum* cv. WL711 as well as *T. durum–Ae caudata* and *T. durum–Ae* umbellulata amphiploids were crossed with

the Chinese Spring line carrying *Ph* suppressor system (from *Aegilops speltoides*) to induce homoeologous pairing and reduce the linkage drag through GISH and molecular marker aided selection. F_1's of the crosses of two substitution lines, 5U of *Ae triuncialis* for 5A of *T. aestivum* cv. WL711 and 5M of *Ae ovata* for 5D of WL711 carrying genes for rust resistance, with Chinese Spring carrying Ph^1, were backcrossed to WL711. Rust resistant backcross derivatives were characterized with a set of sequence tag microsatellite (STMS) markers of wheat. The study showed that rust resistance gene(s) from both the alien substituted chromosomes were transferred to wheat with reduced alien chromatin (Aghaee-Sarbarzeh, Harjit-Singh and Dhaliwal, unpublished data). Similarly, induced transfer of rust resistance genes from *Ae. caudata* and *Ae. umbellulata* into wheat by crossing of *T. durum–Aegilops* species amphiploids with Chinese Spring (Ph^1) and characterization of derivatives using microsatellites has shown that in some of the derivatives chromosomal exchanges between the alien chromosomes and their homoeologous wheat chromosomes carrying gene(s) for resistance has taken place (Aghaee-Sarbarzeh, Harjit-Singh and Dhaliwal, unpublished data). Also, efforts are being made to tag the alien disease resistance genes with molecular markers in various other interspecific derivatives developed through wide hybridization. Molecular linkage map of the diploid donor species, *T. monococcum*, has been constructed (Pal *et al.*, 1997) and work is in progress to saturate the molecular linkage map as well as to identify molecular markers for leaf rust, stripe rust, Karnal bunt, the cereal cyst nematode and weedicide resistance genes.

GERMPLASM ENHANCEMENT USING GENETIC STOCKS

In a pre-breeding program to improve the agronomically superior spring wheat cultivars WL711 and HD2329, a number of genes for resistance to leaf rust, quality characters and other desirable traits have been transferred from various genetic stocks (Table 3). It may be desirable to test the improved rust resistant bread wheat lines carrying rust resistant genes which have yet not been tried in East Africa. Similarly, the novel variability for other traits available in the background of cultivars WL711 and HD2329 could be utilized in bread wheat improvement programs of Africa.

MOLECULAR TAGGING OF GENES OF ECONOMIC IMPORTANCE

Since the heritability of many traits of economic importance is low, their improvement through direct selection becomes tedious. In such cases, identification of molecular markers linked to genes governing these traits facilitates selection for these traits through marker aided selection (MAS). Keeping this in view, populations were developed to find molecular markers for grain protein content, pre-harvest sprouting tolerance and seed size in bread wheat. Screening of contrasting parents and recombinant inbred lines (RILs) developed from crosses between them with various molecular markers (Table 4), resulted in identification of markers linked with these traits.

TESTING OF IMPROVED GERMPLASM IN EAST AFRICAN COUNTRIES

Rust diseases are one of the major constraints in wheat production in East African countries including Ethiopia. Like other air-borne pathogens, new pathotypes of these rusts, virulent on already deployed resistance genes, evolve thereby reducing the useful life of newly bred cultivars. In Ethiopia, two recently developed durum wheat cultivars with high yield potential succumbed to stripe rust. Therefore, it becomes necessary to introduce novel rust resistance genes that can provide long term resistance. The evaluation of improved stocks with

resistance genes from the wild relatives as well as other genetic stocks in both *T. durum* and *T. aestivum* backgrounds will be desirable. The improved resistant lines are available for evaluation in respective wheat growing areas. Similarly, *T. durum* derivatives with high SDS sedimentation value (and thus higher gluten strength) could be utilized for improving the African cultivars for durum products, such as pasta. The evaluation of these lines for direct introduction could provide cultivars with high quality of durum products.

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Questions and Answers:

Ravi P. Singh: Most wide cross programs look for chromosome segments as small as possible worrying about undesirable traits that may be present in the longer segments. I suggest that all transfers, even longer ones, must be maintained and perhaps evaluated for genes other than the targeted resistance genes.

Answer: All interspecific derivatives carrying large alien segments as well as those with complete substituted/added alien chromosomes are being maintained and evaluated for other desirable traits. However, for effective commercial utilization of alien genes with minimum linkage drag, one needs to select for small alien segments.

Table 1. Wide hybridization for transfer of desirable traits from wild *Triticum* and *Aegilops* species.

Donor species with genome(s)	Character(s)	No of sources utilized	Recurrent parent
Triticum urartu (A^u)	- Stripe rust* - New HMW subunits (Ax + Ay)	1 3	*T. durum* - do -
T. boeoticum (A^b)	- New HMW subunits (Ax + Ay)	2	*T. durum*
T. araraticum (AG)	- Leaf rust - Stripe rust - Powdery mildew - HMW glutenin subunits (Ax, Gx + Gy)	6 2 2 1	*T. durum* - do - - do - - do -
T. dicoccoides(AB)	- Stripe rust - do - - HMW sub units (Ax, Ax + Ay)	1 1 3	*T. durum* *T. aestivum* *T. durum*
Ae. squarrosa (D)	- Leaf rust - Karnal bunt	1 1	*T. aestivum* - do -
Ae. ovata (UM)	Leaf rust, stripe rust, powdery mildew, karnal bunt, cereal cyst nematode	1	*T. aestivum*
Ae. triuncialis (UC)	- do -	1	*T. aestivum*
Ae. caudata (C)	- do -	2	*T. aestivum*
Ae. umbellulata (U)	- do -	2	*T. aestivum*

* alien resistance gene for the respective disease mentioned in this column.

Table 2. Effect of transfer of novel alien high molecular weight glutenin subunits from wild *Triticum* progenitor species into *T. durum* cv. PBW34 on SDS sedimentation value.

Donor species	Accession number	Novel HMW subunit from donor line	Identification number	Generation	SDS sed. value
T. boeoticum	7115	Ax + Ay	L98/99-10-3	BC_4F_3	75.0
T. urartu	5301	Ax + Ay	L98/99-13-1	BC_2F_5	64.0
		-do-	L98/99-15-3	BC_2F_5	61.5
		-do-	L98/99-16-3	BC_2F_5	56.0
		-do-	L98/99-26-5	BC_3F_2	57.5
		-do-	L98/99-27-10	BC_3F_2	75.0
	5340	-do-	L98/99-33-8	BC_2F_2	71.5
T. dicoccoides	4630	Ax	L97/98-119-1	BC_3F_3	49.0
	4632	Ax + Ay	L96/97-1-7	BC_2F_5	54.0
	7070	Az + Ay	89	BC_2F_5	66.0
T. araraticum	4224	Ax, Gx + Gy	55-4	BC_2F_3	48.5
Check					
T. durum cv. PBW34					38.0

Table 3. Pre-breeding of two agronomically superior spring wheat cultivars WL711 and HD 2329.

S. no.	Character	Genes/source(s)/description
1	Leaf rust resistance	*Lr 9, Lr 19, Lr 22a, Lr 24, Lr 32, Lr 34, Lr KLM4-3B*
2	Stripe rust resistance	*Yr 9, Yr 10*
3	Karnal bunt resistance	Major genes from HD 29
4	Powdery mildew resistance	From *T dicoccum* line NP 200
5	Bread making quality	Novel HMW glutenin sub units "5 +10" (from UP301)
6	High protein content	Two major genes from PH 132 and PH 133
7	Height	Lines with both *Rht 1* and *Rht 2* and only *Rht 1*
8	Agronomic characters	Lines with - bold seed - long head - multifloret - oligoculm character with strong stem - branched ear - narrow erect leaves
9	Sprouting tolerance	- Major genes from Acc8198

Table 4. Molecular tagging of genes for protein content, pre-harvest sprouting tolerance and seed size.

Trait	Cross		Population used for molecular tagging	Genetic control	Molecular markers liked with the trait
	Parent I	Parent II			
Grain protein content	WL711 (low)	PH132 (high)	RILs*	Two major genes and QTLs	1. STMS marker (*wmc*41) associated with QTL on 2DL (Prasad *et al.,* 1999) 2. IISR marker ($UBC844_{1100}$) linked with QTL on 7AS (Dholakia *et al.*, unpub. data)
Pre-harvest sprouting tolerance	HD2329 (susceptible)	SPR8198 (tolerant)	RILs	One major gene and QTLs	1. STMS marker (*wmc*104) on 6B (Roy *et al.*, 1999) 2. STS marker (MST101) on 7D (Roy *et al.*, 1999)
Seed size	Chinese Spring (small)	Rye Sel 111 (high)	RILs	Polygenic	1. Two RAPD markers (Kaur *et al.*, unpublished data)

* Recombinant inbred lines.

QUALITY OF ETHIOPIAN DURUM WHEAT CULTIVARS

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ABSTRACT

Eleven Ethiopian durum wheat (*Triticum turgidum* var. *durum*) cultivars were evaluated at five environments in Ethiopia for two years for 1000 kernel weight, protein concentration, gluten strength, mixogram time, mixogram height, flour color and kernel yellow berry. Gluten strength was measured by the sodium dodecyl sulfate (SDS) sedimentation test. Gliadin and glutenin proteins were electrophoretically assessed to investigate associations between these proteins and gluten strength. Significant differences between the genotypes were observed for 1000 kernel weight, protein content, gluten strength, flour color and yellow berry. Six different patterns were identified for HMW glutenin subunits with the combination null and 20 being the most common. For *Glu-B1*, the alleles producing protein subunits 20 and 7+8 were the most common. The 6+8 allele was less frequent. Three cultivars expressed the LMW-1 pattern while the remaining eight cultivars had pattern LMW-2. The strongest gluten strength corresponded to the mixed subunits 7+8/6+8 and 7+8/20, followed by subunits 6+8 and 7+8. Subunit 20 was associated with the lowest gluten strength. LMW-2 was more strongly associated with greater gluten strength as compared to LMW-1. The effects of LMW and HMW glutenin subunits were additive. To develop high quality durum wheats, LMW-1 and subunit 20 HMW genotypes should be discarded, and electrophoretic analysis and SDS-sedimentation tests used to identify superior germplasm.

INTRODUCTION

Durum wheat (*Triticum turgidum* L. var. *durum* Desf.) is widely known to produce superior pasta products because of its kernel size, hardiness, and golden amber color. Cooked pasta prepared from durum wheat semolina retains firmness and elasticity and is resistant to surface disintegration and stickiness. These characteristics tend to be cultivar dependent (Dexter and Matsuo, 1977; Autran *et al.*, 1986; Feillet *et al.*, 1989). Autran and Galterio (1989) pointed out that an essential element of pasta cooking quality is the ability protein components to interact during pasta processing resulting in insoluble aggregates and viscoelastic complexes that entrap starch granules limiting surface disintegration of pasta during cooking. Gliadin and glutenin proteins interact in the presence of water to form glutenin, the protein complex responsible for the viscoelastic properties that make durum wheat superior for pasta making (Peña *et al.*, 1994).

The viscoelasticity of cooked pasta correlates with protein content and type (Damidaux *et al.*, 1980; Kosmolak *et al.*, 1980; Du Cros, 1987). Researchers (Galterio *et al.*, 1993; Mariani *et al.*, 1995) have indicated that when durum wheat protein concentration falls below 11 %, inferior

pasta quality occurs. Gluten composition is the primary factor determining the quality characteristics of durum wheat cultivars (Vazquez *et al.*, 1996). Glutenins can be electrophoretically divided into high (HMW) and low (LMW) molecular weight subunits. HMW subunits are encoded by genes on the long arm of group 1 homoeologous chromosomes (*Glu-A1, Glu-B1*, and *Glu-D1*) whereas the genes encoding the LMW subunits are clustered on the short arm (*Glu-A3, Glu-B3*, and *Glu-D3*) of the same chromosomes, tightly linked to the *Gli-B1* complex loci which encode for γ-gliadin 42 and γ-gliadin 45 (D'Ovidio *et al.*, 1992; Payne *et al.*, 1984; Shewry *et al.*, 1986; Payne, 1987).

Two LMW glutenin subunit patterns, LMW-1 and LMW-2, largely explain quality differences between some durum wheat genotypes. LMW-2 glutenin subunits confer superior quality with respect to genotypes possessing LMW-1 (Vazquez *et al.*, 1996; D'Ovidio, 1993). Ruiz and Carillo (1995) indicated that, in general, lines with the LMW-2 pattern had significantly greater SDS sedimentation value and better mixograms than those with the LMW-1 patterns. The γ-gliadin components 42 and 45 are only genetic markers, without any direct involvement in dough quality.

Assessing the relationship between durum gluten strength and glutenin properties, Carillo *et al.* (1990) found that HMW subunits 6+8 and 7+8 were more commonly associated with superior quality subunit 20 with poorer quality. Autran and Feillet (1987) reported no significant differences between SDS means of durum genotypes with subunit 6+8 or 7+8. Genotypes with subunit 20 however, had weaker gluten strength. Peña *et al.* (1995) pointed out that subunits 6+8 and 7+8 showed significantly better durum quality than subunit 20, and, the subunit pair 6+8 was associated with significantly higher SDS values when combined with LMW-2 than with LMW-1. Pogna *et al.* (1990) indicated that gluten subunit 7+8 gave greater SDS sedimentation volume and higher elastic recoveries than subunits 6+8 and 20, and the positive effects of LMW-2 gluten subunits and HMW subunit 7+8 were additive.

Yellow color pigmentation in semolina and in the finished pasta products is a desirable quality characteristic of durum wheat. Durum contains xanthophylls (yellow pigment) and lacks lipoxidase enzyme, which destroys the yellow pigment during processing. Joppa and Walsh (1974) observed that durum genotypes differ in xanthophylls and lipoxidase quantity and quality.

Ethiopia is the largest producer of durum wheat in Sub-Saharan Africa and is considered to be a center of genetic diversity for this species of wheat (Vavilov, 1951). However, very little emphasis has been placed on improving the nutritive or processing quality of durum wheat in Ethiopia. In this study, eleven durum wheat cultivars released in Ethiopia between 1966 and 1996 were evaluated for agronomic and nutritive and processing quality characteristics.

MATERIALS AND METHODS

Eleven durum wheat cultivars released in Ethiopia between 1966 and 1996 were included in the study (Table 1). The materials were planted in five diverse and typical durum wheat growing environments (Debre Zeit, Akaki, Chefe Donsa, Bichena and Alem Tena) across the country during the 1995 and 1996 main cropping seasons. Debre Zeit and Akaki are mid-altitude environments (1900-2300 m a.s.l.) characterized by moderate annual rainfall (700 - 900 mm) and well drained black Vertisol soils. Chefe Donsa and Bichena are highland (>2300 m a.s.l.) environments characterized with high annual rainfall (>1000 mm) and poorly drained black Vertisol soils. Alem Tena is a lowland (< 1900 m a.s.l.) site located in the Rift Valley and with

well-drained sandy soil, and an annual, erratic rainfall of 500 mm. A randomized complete block design with three replications was used. Plot sizes were 6m x 2m. Fertilizer was applied at the rate of 100 kg ha^{-1} diammonium phosphate (DAP) and 100 kg ha^{-1} urea. DAP was all applied at planting time whereas urea was split-applied, especially at the high rainfall environments. Other cultural practices were based on local recommendations.

Total grain protein extracts were separated by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE), using 10% polyacrylamide gels. High and low-molecular weight glutenin subunits were designated according to the nomenclature system of Payne and Lawrence (1983) and Payne *et al.* (1984).

Whole meal and flour quality assessment tests were conducted by the Wheat Quality Laboratory, at CIMMYT headquarters in Mexico. Whole meal samples were generated with a "Udy Cyclone" mill (Udy CO., Colorado, USA), fitted with a 0.5 mm screen, while flour samples were produced with a Brabender Jr. mill (Brabender OHG, Duisburg, Germany), fitted with 9XX mesh sieve. Gluten strength was estimated by the SDS-sedimentation test on 1-g meal or flour samples as described by Peña *et al.* (1990). Grain and flour protein were determined by NIR analysis using an Infralyzer 350 (Technicon Instruments Corp., Tarrytown, New York, USA) calibrated for protein (N X 5.7) as determined by the Kjeldahl procedure of the AACC (1983). Grain and flour color were determined with a Minolta (Minolta CO., N. Jersey, USA) Color Meter ("b" value), following manufacturer's instructions. Dough mixing time and mixogram peak height (recording paper size), were determined on 10-g flour samples with a Mixograph (National Mfg, Co. Chicago, Ill., USA) following method 54-40A of the American Association of Cereal Chemists (AACC, 1983). Yellow berry (%) was determined visually in 20-g grain samples.

Separate physical, chemical and alveograph analysis of a subset of the tested cultivars, plus the recently released cultivars Tob66 and Asasa, was performed by Kaliti Food Share Co., Ethiopia.

Data were analyzed using the SAS statistical program (SAS Institute, 1985). Fisher's Protected Least Significant Difference Tests (LSD) were used for means separation when the F-test indicated significant differences for genotypes. Flour quality data is presented only for the second year (1996) of testing. Samples from the three field replications were combined to generate this flour quality data, and hence, no statistical analysis was carried out on flour quality data. Homogeneity of error variance was tested before combining data across locations.

RESULTS AND DISCUSSION

Cocorit 71 and Kilinto exhibited the poorest yellow berry percentage, while Kilinto, Gerardo and Boohai had the highest 1000 kernel weight (Table 2).

On a whole meal basis significant differences between the cultivars were found for protein concentration, SDS sedimentation volume and yellowness (Table 2). Grain protein among the cultivars ranged from 10 % to 12.3 %. Gerardo, Foka and Fetan had grain protein concentrations of 12 % or higher. Cocorit 71 exhibited a significantly higher SDS sedimentation volume than the other cultivars, based on whole meal data, though Foka, Yilma, and Kilinto also had relatively high SDS values. Quamy, Ld 357 and Fetan exhibited the lowest SDS values. Flour protein concentration correlated positively with whole meal protein. Flour SDS values were higher, but in general, followed a similar pattern. The cultivars Yilma, Foka and Cocorit 71 had the highest flour SDS values (Table 3). The longest mixing time was also observed for Cocorit

71, Yilma and Kilinto. The cultivars Yilma, Foka and Boohai had the highest mixogram height. Ld 357, Bichena, Boohai, Fetan and Yilma exhibited the highest whole meal yellowness (Table 2) and flour color (Table 3).

HMW and LMW glutenin subunits

Six patterns were identified for HMW glutenins with the alleles null and 20 being the most common. Representing *Glu-B1*, the alleles 20 and 7+8 were the most common. Less frequent was the 6+8 allele. Yilma was bi-morphic for 20 and 7+8 as was Cocorit 71 with 7+8 and 6+8. Gerardo, Ld 357, and Quamy had pattern LMW-1 and the remaining eight cultivars had pattern LMW-2 (Table 4) glutenin subunits.

The relationship between HMW and LMW glutenin subunits and durum quality is summarized in Table 5. Significant differences were observed between the six HMW subunits for whole meal protein, whole meal SDS, yellow berry, and yellowness. The strongest gluten strength was associated with the subunit pair 7+8/6+8 (Cocorit 71) followed by 7+8/20 (Yilma) and 6+8 (Kilinto), while subunit 20 was associated with the poorest gluten strength (Quamy and Fetan) (Tables 2 and 4).

Cultivars with LMW-2 had significantly greater gluten strength than those with LMW-1 as indicated by SDS sedimentation volumes (Table 5). Various researchers (D'Ovidio, 1993; Ruiz and Carillo, 1995; Porceddu *et al.*, 1998) have also reported that band LMW-2 is responsible for endowing semolina with better properties. The effects of the LMW and HMW glutenins on gluten quality appear to be additive because cultivars showing glutenin patterns LMW-2 in association with HMW glutenin subunits 6+8 and 7+8 were among those characterized by the best gluten quality (Cocorit 71 and Kilinto) (Table 2 and Table 5). This type of additive response was also reported by Boggini *et al.* (1997).

Quality analysis by the Kaliti Food Share Company

Analysis by Kaliti Food Share Co., indicated that six of the released cultivars had amber and extra hard (AEH) kernels, a requirement for quality pasta products (Table 6). Most of the cultivars (except DZ04-118 and Gerardo) met the hectoliter weigh standard. The standard set for extra hard/soft texture ratio is 90/10, and six of the cultivars passed this standard, with Asasa exhibiting a ratio 100/0, indicating superiority for this trait (Table 6).

Cultivars Tob 66, Asasa, Boohai and Quamy had wet gluten values within the standard range (27-36). The varieties Tob 66 and Asasa were quite outstanding in this regard with wet gluten percent of 35.80 and 32.70, respectively. Tob 66, Asasa, Boohai, Quamy, Kilinto, Foka and Gerardo exhibited protein concentrations ranging from 13.0 to 15.4, well within the industrial standard range.

The Chopin Alveograph Analysis indicated that Tob 66, Quamy and Kilinto performed well for dough resistance. For dough expansion, only Tob 66, Kilinto and Gerardo met the industrial requirement. None of the cultivars had values within the standard range for dough extensibility. Based on their overall analysis, Kaliti has recommended Tob 66, Asasa, Boohai, Quamy, Kilinto and Foka (in this order) as being superior for pasta products.

CONCLUSIONS

Pasta products made from durum wheat semolina require adequate level of protein for proper processing characteristics, nutritional value and overall quality. Most lines evaluated in this study had adequate levels of protein. In spite of the fact that qualitative traits such as protein content and gluten strength neither conferred adaptive advantage nor underwent intentional selection pressure in Ethiopia, variation for SDS sedimentation volume was found in the germplasm studied (2.6 - 6.9 ml). The cultivars Cocorit 71, Foka, Kilinto and Yilma had the highest gluten strength. Foka was a superior genotype for most quality parameters. Gerardo, Ld 357 and Quamy, exhibited poor gluten strength.

However, this study has shown that in a durum quality breeding program, it is more effective to discard germplasm based on low molecular weight glutenin patterns (LMWG), the deleterious casual proteins, because high molecular weight glutenins (HMWG) can be associated with two different patterns of LMWG, as has been demonstrated in this study. Genotypes with LMW-1 and HMW glutenin subunit 20 should be discarded, as well. Combined electrophoretic analysis with SDS sedimentation are effective tools to select genotypes of durum wheat with good viscoelasticity and pasta firmness. The SDS test and the mixogram are effective in detecting the genetic variance related to gluten properties.

SDS allows early generation selection since lines chosen for high SDS values maintain good characteristics when grown in different locations and years. Protein content, on the other hand, is highly influenced by the environment. Genetic expression of protein content must therefore be measured with reference to environmental conditions.

These results, in addition to identifying genetic diversity for specific quality parameters, can be useful in planning more effective durum wheat breeding strategies. However, since the quality analysis by the authors and the analysis made by the Kaliti Food Share Company differ in some respects, there may be a need to repeat this experiment across more years and locations.

ACKNOWLEDGMENTS

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Questions and Answers:

Ravi P. Singh: Bread wheats carrying the *Lr19* gene for leaf rust resistance have higher pigment levels than the best durum wheat; what is the possibility of developing bread wheat for pasta production?

Answer: It is possible as long as these bread wheats have a low amount of lipoxidase which destroys the pigment during processing.

Wolfgang H. Pfeiffer: Several of the recently released cultivars carry unfavorable alleles such as HMW GLU-B1 20 and GLIADIN 1. Do you plan in the future to correct these deficiencies via e.g. progenitor building through the backcross method?

Answer: Yes, we do. In fact, the crossing of these lines has already started at Debre Zeit.

Table 1. Year of release, pedigree and origin of the eleven durum wheat cultivars tested for quality in 1995 and 1996.

Cultivar	Year of release	Pedigree	Origin	1000 Kern. Wt.	Yellow Berry
				---gm---	---%---
DZ04-118	1966	Improved Landrace	Ethiopia	34.6	14.2
Cocorit 71	1976	--	CIMMYT	39.9	23.0
Gerardo	1976	VZ466/61-130xLdsxGII's'CM9605	CIMMYT	40.7	18.1
Ld 357	1979	Ld 357/CI,8155ND58-40	U.S.A	32.9	21.0
Boohai	1982	Coo's'/CII,CD 3862-BS-1BS-0GR	CIMMYT/Ethiopia	40.1	12.2
Foka	1993	Cit 71/CII, CD 3369	CIMMYT/Ethiopia	37.8	15.9
Kilinto	1994	Iumillo/Inrat 69/BHA/3/Hora/4/ Cit 71/Joro, DZ 918	CIMMYT/Ethiopia	41.4	24.0
Bichena	1995	Iumillo/Cocorit 71, DZ 392-2	CIMMYT/Ethiopia	39.1	14.9
Fetan	1996	Tob 2	CIMMYT/Ethiopia	38.1	8.9
Quamy	1996	AOS//PGO/CII/3/JO 69/CRA//GS/ SBA 81/3/FGO/			
		CRA/5/FGO/DON/6/HUICD75533-A			
Yilma	1996	DZ864-12	CIMMYT/Ethiopia	41.7	8.2
LSD				2.15	0.84
Mean				38.7	16.4
CV(%)				10.9	10.0
Std. Dev.				7.4	14.6

Table 2. Quality parameters for eleven durum wheat cultivars grown across five locations during 1995 and 1996.

Cultivar	WM Protein --%(12%M.B.)--	WM SDS Sed. --ml--	WM Yellowness Minolta'b'	HMW(*Glu-A1*)	HMW(*Glu-B1*)	LMW(*Glu-B3*)
DZ04-118	11.3	5.3	15.3	0	7+8	2
Cocorit 71	10.0	6.9	13.4	0	7+8/6+8	2
Gerardo	12.3	5.0	15.4	0	6+8	1
Ld-357	11.3	3.9	16.2	0	7+8	1
Boohai	11.8	5.5	16.2	0	20	2
Foka	12.0	6.1	15.5	0	20	2
Kilinto	10.0	6.0	14.9	0	6+8	2
Bichena	11.9	5.6	16.3	0	20	2
Fetan	12.0	4.5	16.1	0	20	2
Quamy	10.9	2.6	15.3	0	20	1
Yilma	11.6	6.1	16.6	0	7+8/20	2
LSD	0.13	0.15	0.24			
Mean	11.4	5.2	15.6			
CV(%)	2. 3	5.7	3.0			
Std. Dev.	3.0	1.3	1.9			

Table 3. Flour quality data (unreplicated) for eleven durum wheat cultivars grown during 1996.

Cultivar	Flour Protein % (14 % M.B.)	Flour SDS Sed. --ml--	Mixing Time --min--	Mixing Ht. paper scale	Flour Color Minolta'b'
DZ04-118	10.5	5.1	3.6	3.4	13.9
Cocorit 71	9.2	8.7	3.9	3.5	10.5
Gerardo	11.5	6.1	2.7	3.8	14.5
Ld 357	10.5	3.9	2.1	3.5	15.7
Boohai	10.4	6.8	3.2	4.0	15.1
Foka	11.5	8.8	2.9	4.1	13.8
Kilinto	10.2	7.6	3.3	3.5	14.0
Bichena	10.6	7.8	2.8	3.8	15.5
Fetan	11.0	5.4	2.7	3.9	14.9
Quamy	10.3	2.7	2.9	3.5	14.9
Yilma	10.8	9.7	3.8	4.0	15.8

Table 4. Mean values for quality characteristics of eleven durum wheat cultivars grouped according to *Glu-B1* and *Glu-B3* controlled low MW glutenin subunit composition.

Subunit Groups	WM Protein % (12% M.B.)	Flour Protein % (14% M.B.)	WM SDS Sed. --ml--	Flour SDS Sed. --ml--	Mixing Time --min--	Mixing Height --Paper scale--	Yellow Berry --%--	WM Yellowness -- Minolta'b'--
Glu-B1								
20	11.1	10.4	4.9	5.9	2.9	3.7	17.9	15.5
6+8	11.2	10.9	5.5	6.9	3.0	3.7	21.2	15.2
7+8	10.9	10.0	5.1	4.6	2.7	3.5	17.7	14.8
7+8/6+8	10.0	9.2	6.9	8.7	3.9	3.5	23.0	13.4
7+8/20	11.6	10.8	6.1	9.7	3.8	4.0	8.2	16.6
Significance level†	**	--	**	--	--	--	**	**
Glu-B3								
LMW-1	11.5 a‡	10.8	3.8 b	4.2	2.6	3.6	19.8 a	15.7 a
LMW-2	11.2 a	10.1	5.7 a	6.5	3.0	3.6	15.9 b	15.4 a
Combinations								
20/LMW-1	10.9	10.3	2.6	2.7	2.9	3.5	20.1	15.3
20/LMW-2	11.2	10.4	5.4	6.6	2.9	3.7	17.5	15.5
6+8/LMW-1	12.3	11.5	5.0	6.1	2.7	3.8	18.1	15.4
6+8/LMW-2	10.0	10.2	6.0	7.6	3.3	3.5	24.0	14.9
7+8/LMW-1	11.3	10.5	3.9	3.9	2.1	3.5	21.0	16.2
7+8/LMW-2	10.8	9.8	5.5	4.9	2.8	3.5	16.5	14.3

† ** - significant at the 0.01 level of probability.

‡ within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 5. Physical, chemical and alveograph analysis of released durum wheat varieties[1].

Variety	Physical Characteristics			Chemical Characteristics*			Chopin dough rest. (P)	Alveograph expansion (G)	Analysis extensibility (L)
	Type	HLW -kg/hl-	E.hard/soft	wet gluten -%-	dry gluten -%-	Protein -%-			
Tob 66	AEH	82.85	97/3	35.80	11.70	15.47	84.70	18.63	70.80
Asasa	AEH	83.50	100/0	32.70	10.68	14.77	71.28	15.88	51.21
Boohai	AEH	82.50	94/6	28.90	10.28	13.90	80.85	16.31	54.00
Quamy	AEH	82.15	99/1	28.90	12.46	13.90	85.52	14.04	40.20
Kilinto	AEH	80.10	94/6	14.50	8.38	13.90	90.75	17.51	62.25
Foka	AEH	81.50	95/5	18.04	7.68	13.04	55.00	15.78	50.80
Cocorit 71	Soft	80.50	5/95	12.60	4.20	10.20	84.00	14.92	45.33
Bichena	AEH&S	85.10	75/25	19.90	7.20	11.86	108.63	16.16	53.00
Ld 357	VEH	80.60	15/85	15.40	6.70	11.86	54.78	13.66	38.00
DZ04-118	WSEH	79.45	30/70	23.05	4.80	10.84	47.12	15.38	48.00
DZ 1640	AEH&S	82.85	71/29	18.04	7.50	11.52	50.82	14.93	45.20
Gerardo	AEH&S	78.60	90/10	33.77	11.26	15.01	55.66	17.81	64.40
Standard		80.00	90/10	27-36	10-12	13-15	85-110	18-22	76-110

[1] Analysis carried out by the Kaliti Food Share Company.

* samples are prepared by extracting the endosperm from each durum wheat sample.

AEH - Amber and Extra hard; HLW - Hectoliter Weight; S - Soft

ON-FARM DEMONSTRATION OF IMPROVED DURUM WHEAT VARIETIES UNDER ENHANCED DRAINAGE ON VERTISOLS IN THE CENTRAL HIGHLANDS OF ETHIOPIA

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ABSTRACT

An on-farm demonstration was conducted for two consecutive cropping seasons (1998-1999) to give farmers the opportunity to compare and evaluate a surface drainage technology, Broadbed and Furrow (BBF), and its associated production package with the traditional system, Ridge and Furrow (RF), on Vertisol areas of Gimbichu, Ethiopia. A total of 39 farmers participated in the trial. Improved durum wheat varieties Kilinto and Foka were grown on 50 x 50 m^2 plots. The results revealed that the mean grain yield of the RF seedbed exceeded the BBF yield by 54 and 120% for the first and second years, respectively. Also, the straw yield of the RF seedbed exceeded the BBF yield by 10 and 16% for the first and second years, respectively. The current results contradict previous reports of superior grain and straw yields using BBF cf. RF and other traditional seedbed preparation methods. This suggests that there may be a gap in the identification of appropriate conditions for utilization of the BBF technology (i.e., in terms of appropriate sowing date, availability of short rains for land preparation, appropriate site selection, intensity and distribution of rainfall, occurrence of frost, or desiccating wind late in the season). The participating farmers reported that the 1998-1999 seasons were characterized by heavy rainfall that started late in the season, and that the intensive rainfall each season surpassed the draining capacity of the BBF system. Farmers' weeding was constrained by the heavy and extended rainfall both years. Therefore, the interaction of the technology and climatic and edaphic factors should be studied further to refine the technology for wider adoption.

INTRODUCTION

Bread wheat (*Triticum aestivum*) and durum wheat (*T. durum*) are widely grown in Ethiopia. Traditionally, durum wheat has been dominant in Ethiopia (Hailu, 1991) though recently the area under bread wheat surpassed the durum area. Durum wheat is mostly grown on black clay soils (Vertisols) and hence farmers refer to it as "*Yekoticha Sinde*" meaning wheat of black soils. Vertisols constitute over 10% the Ethiopian land mass and hence they are agriculturally important to Ethiopia. In Gimbichu woreda, durum wheat accounts for 51% of the total cereal production. However, yields are low because of water logging and low yielding potential of the local cultivars, among others.

A wide range of practices has been developed in order to over come these problems. Traditionally farmers use low yielding crop varieties adapted to poor surface drainage, ridges

and furrows late planting, hand made broadbeds and furrows, and soil burning practices. However, previous studies indicated that with the exception of the hand made broadbeds and furrows, the traditionally applied surface drainage techniques are inadequate to allow the full realization of potential of vertisols. The BBF technology that emanated from precursor traditional practices (Jutzi *et al.*, 1986) was found to adequately satisfy the need for draining excess soil moisture and promotes the advancement of cropping season in order to utilize the potential growing period of these seasonally water logged soils. Using this new practice, higher yields have been reported for many crops (Hailu 1988; Tekalign, 1989; Mesfin and Jutzi, 1993). As a result a Broadbeds and Furrows technology (BBF) is recommended as an alternative solution since this technology has performed well in various locations and years (Mesfin and Jutzi, 1993). According to Jutzi and Mohammed-Saleem (1991) using BBF increases wheat grain yields by an average of 21% and straw yields by 19% as compared to the farmers' ridging method.

It was, therefore, hypothesized that the introduction of improved management of Vertisols along with the high yielding durum wheat varieties may increase productivity. Hence, this experiment was conducted to give farmers the opportunity to compare and evaluate the improved surface drainage technology (BBF) and its packages as compared to the traditional systems (RF).

MATERIALS AND METHODS

The study was conducted for two cropping seasons (1998 and 1999) in Gimbichu watershed areas ($39^0$08' E and $8^0$58' N). The area is characterized as a traditional wheat growing area (2450 m a.s.l.) on Vertisols. Two surface drainage methods (BBF) and the traditional ridge and furrow (RF) were compared on a total of 39 (27 and 12 during the first and second year, respectively) farmers' fields. Out of the 39 farmers that participated in the on-farm trial, 29 grew Kilinto and the remaining 10 grew Boohai, durum wheat cultivars. Twelve of the participant farmers used both BBF and RF, thirteen used BBF while the remaining fourteen used RF only. Each variety was planted on a plot size of 50 x 50 m^2 of land.

Out of the 39 farmers that took part in on-farm trial, 25 farmers used BBF while 26 of the farmers used RF technique of seedbed preparation. The number of ploughings carried out by participant farmers that used the BBF technique of seedbed preparation was four and three for 1998 and 1999 cropping season, respectively. Planting dates in general ranged from the third week of July to fourth week of August. All participant farmers applied fertilizer based on the recommendation from research i.e. 50 kg ha^{-1} DAP and 150 kg ha^{-1} urea.

RESULTS AND DISCUSSION

Grain and straw yields by seedbed type: The grain yield obtained by farmers who used BBF ranged from 440 to 2936 kg ha^{-1}, with a mean of 1272 kg ha^{-1}. Straw yield ranged from 533 to 5877 kg ha^{-1} with a mean of 3459 kg ha^{-1}. Farmers who used RF received grain yield ranging from 1056 to 4538 kg ha^{-1} with a mean of 2293 kg ha^{-1} while straw yield ranging from 1018 to 6662 kg ha^{-1} and a mean of 3851 kg ha^{-1}. This shows there is a significant difference in both grain and straw yields between the two seedbed types. This could be attributed to the extended rainfall situation, favoring the RF method of seedbed preparation which is planted late in the season (Table 1).

The results of both years showed that the mean grain yields of RF seedbed out-yielded that of BBF by 54% and 120% for the first and second years, respectively. Also, the straw yields of RF seedbed exceeded that of BBF by 10% and 16% for the first and second years, respectively (Table 1).

Grain and straw yields by sowing date: Both grain and straw yields varied with sowing date and the minimum grain yield was obtained when planting was done early during the second week of July with the maximum grain yield was obtained when planting was done during the third week of August (Table 1). This has to do, once again, with the prolonged rainfall situation that prevailed during the growing season.

CONCLUSIONS

In general, the improved drainage technology (BBF) production packages did not out yield the traditional (RF) system with local management practices. In fact, it rather significantly reduced the yield. This is against the previous findings that have shown better grain and straw yields using BBF technologies than RF and other traditional seedbed preparation methods. Hence, this study indicates the existence of a gap in the identification of appropriate conditions for utilization of the technology. This could be in terms of appropriate sowing date, availability of short rain for land preparation, appropriate site selection, intensity and distribution of rainfall, occurrence of frost and desiccating wind late in the season, etc. This makes the probability of failure of the technology which the subsistent farmers can not tolerate and hence will undermine the adoption of the technology. Among the participant farmers, those who had quite a long experience of the use of the technology acknowledged that the technology works when favorable conditions prevail. However, they reported that the two seasons were characterized by heavy rainfall that started late in the season, as a result of which the BBFs could not drain the water effectively. In addition, their activities like weeding were also constrained by the heavy and extended rainfall. Consequently, crop yield went far below expectation. Therefore, the interaction of the technology and climatic and edaphic factors should be studied to further refine the technology for its wide adoption and positive impact.

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Questions and Answers:

Efrem Bechere: Your result is contrary to what the Vertisol Project has established for the last 15 years. I feel uncomfortable with this result.

Answer: That is why I brought this paper to this forum. Much is said about the BBF technology, but its adoption is very minimal. So, further research work is required to refine the technology.

Mulugeta Mekuria: Your findings contradict the established advantages of the BBF, indicating RF (traditional farmers' practice) is superior. How was BBF recommended initially? Was it not compared with RF?

Answer: Initially, it was recommended because of its yield advantage over the traditional practices including the RF method. But there is time and place where this technology doesn't work at all. So I wish to identify those factors, rather than giving a blanket recommendation for all Vertisol areas.

Wolfgang H. Pfeiffer: (1) Concrete: which factors/components are you going to improve/change when you use/promote the BBF to farmers in the upcoming season? (2) Out of the 29 farmers who planted the demonstration – did some farmers realize higher yields with BBF?

Answer: (1) I am afraid that I could not exactly identify the factors which should be improved because I am an agricultural extensionist. So I have to receive feedback from the respective scientists to do so and that is the purpose of this paper. (2) In fact, the yield range is different for different farmers but none of them was in favor of BBF.

Table 1. Mean grain and straw yields (kg ha^{-1}) by seedbed type, sowing date and variety in Gimbichu for 1998and 1999 cropping seasons.

	Grain yield		Straw yield	
Particular	**1998/99**	**1999/2000**	**1998/99**	**1999/2000**
Seedbed type				
RF	2382	2204	3726	3976
BBF	1542	1001	4140	3424
% decrease	54*	120*	(-9)	16
Sowing date				
Second week of July	1297	1253	4348	3258
Third week of July	1855	917	4038	3480
Fourth week of July	1619		1381	
Second week of August	1666	2204	2894	3976
Third week of august	2833		4236	

* Significant at the 5% level.

IDENTIFICATION OF ETHIOPIAN WHEAT CULTIVARS BY SEED STORAGE PROTEIN ELECTROPHORESIS

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ABSTRACT

Cultivar identification in wheat is an increasingly important component of genetic improvement programs and germplasm management strategies, protection of Breeders' Rights, quality control and grain marketing. Protein composition is a valuable indicator of genotype genetic identity because protein synthesis is under direct genetic control. Single seeds of Ethiopian bread (15) and durum (10) wheat cultivars and lines were identified on the basis of gliadins and high molecular weight (HMW) and low molecular weight (LMW) glutenin subunit (GS) banding patterns separated by Sodium Dodecyl Sulfate - Polyacrylamide Gel Electrophoresis (SDS-PAGE). HMW-GS, failed to distinguish the cultivars adequately. Gliadin and LMW-GS banding patterns were unique for all cultivars and lines studied, and hence were able to distinguish adequately between wheat genotypes. Therefore, electrophoresis of seed storage proteins are useful in a cultivar development program for germplasm management, seed certification, quality control and registration of newly released wheat cultivars.

INTRODUCTION

The accurate description and identification of wheat cultivars is important for the milling and baking industry. Identity verification of plant is a prerequisite for germplasm management, genetics studies, success in breeding, and for the production of pure foundation and hybrid seed, and the certification process. Cultivar identification will become of greater importance because of Plant Breeders' Rights.

Traditionally, wheat cultivars are identified by evaluating the morphological characteristics of the seed and plant. Morphological characteristics, however, can be unreliable indicators of cultivar's identity. The genetic control of many morphological characteristics is assumed to be complex often involving epistatic interactions, or is often not well understood. Many morphological markers are recessive and therefore only expressed in the homozygous conditions. Furthermore, many morphological attributes are subjected to significant genotype x environment interaction. Hence, morphological appearance may not adequately describe cultivars without extensively replicated trials (Lin and Binns, 1984). An accurate and reliable method for distinguishing and characterizing wheat cultivars and lines is therefore necessary.

Recently, biochemical markers have become a frequent method of ascertaining the identity of cereal cultivars (Cooke, 1984; Wrigley, 1992). As proteins are direct product of structural gene transcription and translation, protein series contain a wealth of genetic information (Wrigley, 1982, 1992). The endosperm proteins of wheat can be fractionated into albumin (extractable in water), globulin (extractable in saline water), gliadin (extractable in aqueous

alcohol solutions), and glutenin (extractable in dilute acid or alkaline) (Wall, 1979). The major storage proteins of wheat are gliadins and glutenin (Wall, 1979; Shewry *et al.*, 1978). Glutenins have been shown to include high molecular weight (HMW-GS) (Payne *et al.*, 1981) and low molecular weight glutenin subunits (LMW-GS) (Jackson *et al.*, 1983). The genes encoding the storage proteins are located at nine main loci and two minor loci on the homeologous chromosome groups 1 and 6 (Payne, 1987).

The analysis of storage proteins by various electrophoretic techniques has been shown to be a valuable method of distinguishing cereal cultivars (Cooke, 1984; Shewary *et al.*, 1978; Wrigley *et al.*, 1982; Wrigley, 1992) and were demonstrated to be independent of site, year and generation of seed production (Marchylo and LaBerge, 1980; Zillman and Bushuk, 1979). Polyacrylamid gel electrophoresis (PAGE) of these proteins is used worldwide as a practical means of identifying cultivars of wheat (Shewry *et al.*, 1979, Jones *et al.*, 1982; DeVilliers and Bosman, 1993; Zillman and Bushuk, 1979; Cooke *et al.*, 1992; Du Cross and Wrigley, 1979), barley (Marchylo and LaBerge, 1980; DeVilliers and Bosman, 1989), oats (Hassen *et al.*, 1988; Lookhart, 1985), rice (Hussein *et al.*, 1989) and maize (Wilson, 1985).

Ethiopia is the second largest wheat producer, after South Africa, in Sub-Saharan Africa with more than 750,000 ha of bread and durum wheat. A large number of new varieties of both bread and durum wheat are being released from the national and regional breeding programs, making cultivar identification more difficult using traditional methods of seed morphology and plant appearance in the field. This paper presents results on identification of Ethiopian-grown wheat cultivars and lines based on SDS-PAGE electrophoresis of three classes of seed storage protein from single kernels.

MATERIALS AND METHODS

Wheat Cultivars

A total of 25 Ethiopian wheat cultivars and advanced lines (15 bread wheat and 10 durum wheat) were examined for gliadin, HMW- and LMW-GS composition. Table 1 presents year of release, area of coverage, and crosses of wheat cultivars and lines studied. These cultivars currently cover most of the area allotted to improved bread and durum wheats in Ethiopia; the advanced lines are derived from the breeding program and have good potential for future release. All wheat materials were kindly provided by the wheat improvement programs at Debre Zeit, Holetta and Kulumsa and were multiplied in the greenhouse in 1999 at the Orange Free State University, South Africa.

Extraction of Storage Proteins

The different storage proteins were extracted from six random single kernels from each wheat cultivar/lines. Kernels were individually crushed to a powder with a mortar and pestle. The ground kernels were then placed in individual 1.5 ml eppendorf tubes.

Glutenin protein extraction: The sequential extraction procedure of Singh *et al.* (1991) was used to obtain HMW- and LMW-GS. In this procedure, gliadins were first extracted by heating in a 60 °C in a waterbath for 1 hr. in 300 µl 70% aqueous ethanol and was then removed. The residue in each eppendorf tube was then washed twice by adding 1 ml 50% n-propanol, vortexed briefly, incubated in a 60 °C in a waterbath for 30 min. and all n-propanol was sucked off after centrifugation at 10,000 rpm for 2 min. The HMW- and LMW-GS were

extracted from the gliadin-free residue by incubating in a 60 °C waterbath in 120 µl extraction buffer [50% n-propanol in 0.08 M Tris-HCl (pH 8.0) containing freshly added 1.25% (w/v) dithiothreitol)]. After a brief initial vortexing, samples were again incubated in extraction buffer containing 0.17% 4-vinyl-pyridine. After centrifugation, the supernatant was collected in a new tube then mixed with an equal volume of sample loading buffer [0.08 M Tris-HCl (pH8.0), 20% (v/v) glycerol, 1.6% (w/v) SDS and 0.016% (w/v) bromophenol blue].

Gliadin extraction: Gliadin proteins were extracted from ground single wheat kernels by incubating for 1 hr at 60 °C in 300 µl extraction buffer (18% urea consisting of 1% *2*-mercapto-ethanol [2-Hydroxyethylmercaptan; β-Mercaptoethanol]), vortexed briefly at every 30 min. interval, the supernatant was collected in a new tube and mixed with an equal volume of sample loading buffer.

Polyacrylamide Gel Electrophoresis

Sodium dodecyl sulphate-polyacrylamide gel electrophoresis (SDS-PAGE), as described by Maartens (1999), was performed on a vertical slab gel electrophoresis unit, Model SE 600 System (Hoefer Scientific Instruments, San Francisco, CA). A separating gel of 10% acrylamide and 1.5% crosslinker and a stacking gel of 5.7% acrylamide and 1.2% crosslinker concentration were used. Forty microliters of protein samples were loaded into the stacking gel sample wells with a disposable-tip micropipette. Gels were subject to electrophoresis for at least 3 hr at a constant current of 66 mA per gel. During electrophoresis, the temperature of the system was controlled at 15 °C by circulating water using Multitemp II Thermostatic Circular. The runs were terminated when the tracking dye front had reached the opposite end of the gel.

Gel Staining

Gels were stained following the procedure developed by Wrigley (1992). Gels were first immersed for at least 4 hr in a fixing solution composed of acetic acid, methanol and distilled water at 1:4:5 ratio. Then, gels were stained overnight with a solution composed of 0.58% (w/v) Coomassie Brilliant Blue G 250 in a 14% (w/v) trichloroacetic acid containing 5%(v/v) methanol and 200-ml distilled water. The background coloration of the gel was removed by destaining the gels frequently in distilled water at room temperature before examination.

Gel analysis and Interpretation

For the identification of HMW-GS and allele classification at each of the Glu-1 loci, the nomenclature proposed by Payne and Lawrence (1983) was used. Assignment of HMW-GS identification numbers was based on comparisons with assignments of the South African wheat cultivars the standard varieties Tugela (2*, 1+8, 5+10) and Verbeterde Kenia (1, 17+18, 2+12).

Gliadin and LMW-GS compositions of wheat cultivars/lines, relative to the banding patterns of a reference cultivar Chinese spring, were analyzed using the Molecular Analyst Finger Printing System (BioRad Labs, Hercules, CA). The migration distance of proteins was determined from a densitometric curve of every replication of each cultivar. Only bands with intensity of more than 15 were accepted. Relative staining intensities of the bands were

determined according Bushuk and Zillman (1978) on a 1 to 5 scale; the lightest bands were given a value of 1 and the darkest bands a value of 5.

RESULTS AND DISCUSSION

HMW-GS composition: High degree of homogeneity is an important criterion for variety release, grain marketing and farmers' selection of cultivars. In this study, all genotypes examined were homogeneous for HMW-GS composition. The cultivars and lines grouped according to their *Glu-1* alleles are presented in Table 2. In bread wheat, nine *Glu-1* alleles were identified, three at *Glu-A1*, four at *Glu-B1* and two at *Glu-D1*. In durum wheat, six *Glu-1* alleles, one at *Glu-A1* and five at *Glu-B1* locus were identified.

On the basis of HMW-GS composition, the 15 bread wheat cultivars were divided into eight groups and the 10 durum wheat cultivars and lines in to five different groups. In both bread and durums, three groups were represented by three varieties each and one group in bread wheat was represented by two varieties. Four groups in bread wheat and two groups in durum wheat had only one cultivar each. In bread wheat, three groups carried subunit 1 and three others subunit 2* at the *Glu-A1* locus. Since the HMW subunit 2* at the *A1* locus and subunit 2 at the *D1* locus co-migrate on 10% polyacrylamide gels, two groups of bread wheat were assigned subunit Null/2*. At the *Glu-B1* locus, three groups carried subunit 7+8, three others carried subunit 7+9, and two different groups carried subunits 6+8 and 17+18 each. At *Glu-D1* locus, four groups coded for 2+12 subunit and all others coded for 5+10 subunits. In durum wheat each group coded for one subunit at *Glu-B1* and all carried a null allele at *Glu-A1*. Branlard *et al.* (1989) showed that over 80% of a collection of 404 durum wheat varieties lacked HMW-GS encoded at *Glu-A1* locus, containing only subunits at *Glu-B1*.

LMW-GS composition: The LMW-GS banding patterns were related to the nomenclature system developed by Gupta and Shepherd (1988) for Australian wheat cultivars. Table 3 presents different banding combinations for the 15 bread and 10 durum wheat cultivars and lines studied. The results indicated that all wheat cultivars/lines were adequately discriminated by LMW-GS profiles. The banding patterns of cv. Enkoy, Arendato, Foka, Kilinto and Quamy in group 2 and cvs. HAR 1685, HAR 710 and HAR 604 in group 3 did not match with any of the combinations in the nomenclature and hence were considered to be new combinations. Two banding combinations were expressed by three bread wheats (Mamba, Pavon 76 and Dashen) and three durum wheats (Arendato, Bahirseded and Boohai) cultivars in group 1. Most cultivars in both wheat species had combination 'f' alone or combined with combination 'a', 'c' or 'b' in group 1. In groups 3, the second slow- and fast-moving bands did not appear in cv. HAR 1709 and DZ- 1640. In group 2, the third, the first and the second slow-moving bands respectively did not appear in K 6295-4A, Gara and HAR 710 profiles. Kilinto and Quamy had combination 'f' in group 1, but in group 2 the pattern did not match to any one of the patterns in the nomenclature.

Gliadin composition: The electrophoregram formulas of the gliadin proteins found in the different bread and durum wheat cultivars and advanced lines are presented in Tables 4 and 5. The catalogue indicated that cultivars/lines were readily identifiable by their electrophoretic pattern composed of number and relative mobility of gliadin bands in to the gel. The electrophoregrams of bread and durum wheat were clearly different from each other. None of the durum wheat cultivars/lines contained any gliadins that migrated less than 15 units on relative mobility scale into the gels. Whereas all bread wheat cultivars had at least one band that moved 12 units or less in to the gels. This was attributed to the fact that durum wheats

lack the D genome, which is known to control the synthesis of several gliadins in bread wheats. A total of 31 and 30 gliadin bands were found in bread and durum wheat cultivars/lines, respectively. In both bread and durum wheats, the slow-moving bands were the darkest and the fast-moving bands were the lightest in the intensity. Therefore, faint bands should not be used for cultivar identification purposes. Similarly, De Villiers and Bosman (1993) studying South African wheat cultivars have suggested that band intensities, as they are influenced by protein content, should not be used for cultivar identification unless equal amount of proteins across cultivars are used. In this study, we did not use an equal amounts of proteins for all cultivars and, hence, band intensities should only be used to indicate the presence and concentration of a protein band at a specific position on mobility scale in the gel.

CONCLUSIONS

Visual identification of wheat cultivars has become increasingly difficult because of similarity in seed morphology and plant appearance in the field. Electrophoresis of storage proteins provides protein patterns, which can be used to distinguish easily between cultivars or lines. In this study, a total of 25 Ethiopian wheat cultivars and lines were identified based on their protein banding patterns in SDS-PAGE electrophoresis. Accordingly, LMW-GS and gliadin electrophoresis adequately identified all wheat cultivars studied because each cultivar had a unique banding pattern of these proteins. The HMW-GS, however, classified 15 bread wheat cultivars into eight groups and 10 durum wheat cultivars and lines in to five groups.

Electrophoresis of seed storage proteins has been shown to be operationally simple, fast, reasonable in cost, and allow purity analysis on individual seeds. It has also been indicated as a useful tool to plant breeders, certification seed enforcement agencies and millers because electrophoresis of storage proteins provide an accurate and reliable means for achieving varietal identity, distinction and uniformity with a particular commercial value. The banding patterns of proteins also provide detailed information of germplasm, investigation of pedigree relationships, checking of pedigree validity, assessment of genotypic purity and possible prediction of heterotic combinations. Hence, application of storage protein electrophoretic technique would be of great importance to the Ethiopian wheat improvement program to facilitate cultivar development, germplasm management, seed certification, quality control and registration of new cultivar releases.

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Table 1. Year of registration, production status and crosses of bread and durum wheat cultivars and lines studied.

Cultivar	Year of registr-ation	Prod-uction status	Cross
Bread wheat			
ET-13	1981	S*	UQ105 sel. x Enkoy
HAR 1709	1993	S	BOW28/RBC
K 6290-Bulk	1977	S	(AF.MAYO x GEM) x Romany
K 6295-4A	1980	S	Romany x GB-Gamenya
Enkoy	1974	N	[HEBRAND sel./(WIS 245xSUP 51)]x[(FR-FN/Y).A)
Kanga	1973	N	MENCO x (WIS 245 x SUP 51)/(FR-FN/Y)^2.A
Romany B.C.	1974	N	-----
Mamba	1971	N	(AF.MY48/WIS 245 x SUP 51)x(FR-FN/Y)^2.A
Pavon 76	1982	S	VCM//CNO"S"/7C/3/KAL/BB
Dashen	1984	N/S	KVZ/BUHO"S"//KAL/BB
Batu	1984	N	GLL/CUC"S"/KVZ/SK
Gara	1984	N	AU//KAL/BB/3/WOP"S"
HAR 1685	1994	S	NDVG9144//KAL/BB/3/YACO"S"/4/VEE"S"
HAR 710	1995	S	MRL"S"/BUC"S"
HAR 604	1994	S	4777(2)//FKN/GB/3/PVN"S"
Durum wheat			
Arendato	1967	S	Landrace
Bahirseded	-----	S	Landrace
Boohai	1982	S	CR"S"/21563/61-130 x LDS)Candeal II
Foka	1993	S	Cocorit 71/Candeal II
Kilinto	1994	S	Illumilo/SNRAT 69//Boohai/3/Hora/Jorro/4/CIT
Quamy	1996	S	----
Gerardo	1976	S	Gerardo VZ 466/61-130 x LdS x GII"S"
Cocorit 71	1976	S	RAE/4 TC60// TW 63/3/3/AA
DZ-575	≈ 1995$^+$	--	Boohai/GDO DZ 466/61-130 KGU"S"
DZ-1640	≈ 1998$^+$	--	Hora/CIT"S"//Joo"S"/GS"S"/3/Soo"S"/4/Hora/Respinegro//CM9908/3/RHUM

* S = significant area coverage; N = non-significant area coverage

$^+$ Candidate for release

Table 2. HMW composition of Ethiopian bread and durum wheat cultivars.

Group	HMW subunits			Cultivar
	1A	1B	1D	
	Bread wheat			
1	1	6+8	2+12	Enkoy
2	1	7+8	2+12	K 6295-4A
3	1	7+9	5+10	Dashen,
4	2*	7+8	5+10	K 6290-Bulk, Kanga, Mamba
5	2*	7+9	5+10	Batu, Gara, HAR 1685
6	2*	17+18	5+10	Pavon 76, HAR 710, HAR 604
7	Null/2*	7+8	2+12	ET-13, Romany B.C.
8	Null/2*	7+9	2+12	HAR 1709
	Durum wheat			
1	Null	6+8		Kilinto, Gerardo, Cocorit 71
2	Null	7+8		Arendato, Bahirseded
3	Null	17+18		Boohai, Foka, Quamy
4	Null	13+16		DZ-575
5	Null	23+22		DZ-1640

Table 3. LMW composition of Ethiopian bread and durum wheat cultivars.

Cultivar	LMW subunits		
	3A	3B	3D
	Bread wheat		
ET-13	a	c	c
HAR 1709	a	e	b
K 6290-Bulk	f	e	b
K 6295-4A	f	a	c
Enkoy	c	--	c
Kanga	b	c	a
Romany B.C	c	g	a
Mamba	c/f	g	b
Pavon 76	b/c	c	a
Dashen	b/f	f	d
Batu	f	a	b
Gara	b	a	e
HAR 1685	b	g	--
HAR 710	e	b	--
HAR 604	f	c	--
	Durum wheat		
Arendato	c/f	--	
Bahirseded	a/f	g	
Boohai	c/f	f	
Foka	b	--	
Kilinto	f	--	
Quamy	f	--	
Gerardo	b	c	
Cocorit 71	f	c	
Dz-575	c	g	
Dz-1640	b	g	

Table 4. Electrophoretic formulae of gliadin of Ethiopian bread wheats.

Mobility of bands relative to Chinese Spring standard bands

Cultivar	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
Et-13	5+		5	5	3	3	2	3	3	2	2	2	3	1	1	1	2	1	1	1	1	1
HAR 1709	5	4	5		1	1	2	1	1	2	2	2	2	2	1	1	1	2	1	1	1	1
K6290-bulk	5	5	5		2		3	3	2	2	2	2	1	1	2						2	
K6295-4A	5	5	5		3	3	2	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1
Enkoy	5	4	4	5	4	5	2	2	2	2	2	2	2	1	2	1	1	1	1	1	1	1
Kanga	5	4	5		2	2	1	1	2	2	2	2	2	1	1	1	2	1		2	1	
Romany B.C	5	5	5		1	1	2	2	2	2	2	2	1	2	1	1	1	1	1	1		
Mamba	5	5	5		5		2	3	2	2	1	2	2	1	1	1	1	1	1	1	1	
Pavon 76	5	5	5		3	2	1	2	2	2	1	2	2	1	2			1	1	1		
Dashen	4	5	5	5	1	1	2	4	2	2	2	2	1	2	1			2	1			
Batu	5	5	5		1	1	1	2	3	2	2	2	2	1	2	1	1	1			2	
Gara	5	5	5		1		1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	
HAR 1685	5	5	5	1	3	2	3	2	2	2	2	2	2	1	1	3	1	2	2			
HAR 710	5	5	5		2	3	2	2	1	1	1	2	1	1	1	2	1			1	1	
HAR 604	5	5	5			3	2	2	2	1	1	2		1	1	2	2	1		1	1	

+Relative band intensity, 1 represents the lightest band and 5 represent the darkest band. Scales at the top and bottom of the table indicate position of band on gel.

Table 5. Electrophoretic formulae of gliadin of Ethiopian durum wheats.

Mobility of bands relative to Chinese Spring standard band

Cultivar	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
Arendato		5			5		2 2	2	2	2	3	3	1	2	2	1 1	2 1
Bahirseded		5[+]		5		2	1	3	2	2	2	2	2 1		2	2	2
Boohai		5			4	1	3	2	3	1	1	3	2	2	2	1	1	2
Foka		5		1	4	1	2	3		1	2	2	2	1	1	2	2	1	2
Kilinto	5		5	1	5	1	3	3	3	2	1	2	4	2		2	2	3
Quamy		5	3		4	1	1	1	2	1	1	3	2	2	1	2	2	4
Gerardo	5		5		5		3	3	3	2	3	2	1	1	2	1	2
Cocorit	5		5	4	5	2	1	3	3	4	2	2	2	2	1	1	1	2
DZ-575		5			4	1	3	2	3	2	1	3	2	2	2	2	2	2	2
DZ-1640		5		1	3	1	2	3		1	2	3	1	1	1	2	1	2	2

[+]Relative band intensity, 1 represents the lightest band and 5 represent the darkest band. Scales at the top and bottom of the table indicate position of band on gel.

GENETIC IMPROVEMENT IN GRAIN YIELD AND ASSOCIATED CHANGES IN TRAITS OF BREAD WHEAT CULTIVARS IN THE SUDAN

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ABSTRACT

This study was conducted for two seasons (1997/98 and 1998/99) at Gezira Research Station Farm, Wad Medani, Sudan. The objectives of the study were to estimate progress in genetic improvement of bread wheat (*Triticum aestivum* L.) grain yield, under a heat-stress environments, and identify changes in traits associated with grain yield improvement. Seven bread wheat cultivars released in Sudan from 1960 to 1990 were tested. Yield potential had increased from 2523.5 kg ha^{-1} in 1960 to 3294.8 kg ha^{-1} in 1990. Linear regression of cultivar means on years-of-release showed an increase of 25.7 kg ha^{-1} yr^{-1}($r= 0.55$, $P< 0.01$) in grain yield. This increase in yield was associated with increases of 0.19g y^{-1} in 1000-grain weight, 0.24% yr^{-1} in harvest index, 0.19 day yr^{-1} in grain-fill duration, and a reduction of 0.21 day $year^{-1}$ in duration to anthesis. Considerable progress has been achieved in wheat improvement under heat stress, and breeders have modified a number of traits while selecting for yield *per se*.

INTRODUCTION

The understanding of changes resulting from selection for grain yield and its determinants, by studying the behavior of cultivars released over time, could be useful in determining future selection criteria (Slafer and Andrade, 1991). Analysis of long-term records from cultivar trials and from simultaneous studies of historical genotypes has indicated that genotypic change has made a substantial contribution to the increases in wheat yields (Abbate *et al.*, 1998; Austin *et al.*, 1980; Cox *et al.*, 1988; Hucl and Baker, 1987; Sayre *et al.*, 1997; Siddique *et al.*, 1989a, b; Slafer and Andrade, 1989; Waddington *et al.*, 1986).

In the Sudan, wheat production traces back more than 2000 years, but until the 1940s, it has been restricted to Northern Sudan (16–22° N). Due to increased demand, wheat production has extended southwards to non-traditional areas. These new areas are located in the central and eastern irrigated clay plains, which include Gezira, Rahad, New Halfa, White and Blue Nile schemes. Wheat-growing season in these non-traditional wheat areas is short (90–100 days), and normally with high temperatures during the early and late stages of crop development.

In 1956, a wheat breeding program was initiated in the Sudan to identify adapted cultivars (Elahmadi, 1996). In the past three decades, a local hybridization program, in collaboration with CIMMYT and ICARDA, and national and regional programs, has resulted in the release of adapted varieties that have allowed the expansion of wheat production southward.

However, limited information is available on changes in traits associated with yield improvements under hot environments in the Sudan. Thus the objectives of this study were to (a) estimate progress in genetic improvement of grain yield in bread wheat under heat stress environments, and (b) identify changes in traits associated with grain yield improvement.

MATERIALS AND METHODS

This study was carried out during two years, 1997/98 - 1998/99, at the Gezira Research Farm (GRF), Agricultural Research Corporation (ARC), Wad Medani, located on the clay plain of the central Sudan (14°24′ N, 33° 29′ E, 407 m a.s.l.). The soils of GRF are cracking heavy clay Vertisols, with very low water permeability, pH of ~ 8.5, poor in organic matter (0.5%), deficient in nitrogen (300–400 ppm), and low in available phosphorus (4–5 ppm Olsen extractable P).

Seven bread wheat cultivars that were released in the Sudan, representing different origin and eras of wheat improvement, were used. Details on name, origin, cross, and year of release of these cultivars are given in Table 1. Three sowing dates; early, optimum, and late (1st and 3rd weeks of November, and the 2nd week of December respectively) were used during both seasons of the study. A three-replicate, split-plot design, with sowing dates as main plots and genotypes as sub-plots, was used. Seeding was done manually in rows 20 cm apart and the plots consisted of six rows, 5 m in length. The seeding rate used was 120 kg ha^{-1}. Recommended agronomic packages were applied. No serious lodging or disease incidence was reported. In the first season, due to termite incidence, plots were sprayed and dusted with insecticides: Confidor (imidacloprid 20% EC) and Sevin (carbaryl 85%WP). In the second season, seeds were dressed with a fungicide-insecticide mixture containing Raxil (pencycuron 7.5% WP) and Gaucho (imidacloprid 35% WP) for the control of termites and aphids.

Data recorded included days to flowering, physiological maturity, plant height, grains spike^{-1}, thousand grain weight, and spikes m^{-2}. Excluding the two border rows and 0.5 m from each end, a net area of 3.2 m^2 (four rows by 4 m) was hand-harvested from the ground level. The harvested material was bundled and left to dry for at least 10 days, then weighed, threshed and the grain was weighed again to give biomass and grain yield. Harvest index, grains m^{-2}, and grain-fill duration were calculated.

Analysis of variance was conducted for each season separately, as well as combined analysis over the two seasons. Means were compared using Tukey's test. Rate of increase in grain yield, as well as rate of changes in other associated traits, were estimated by regression analysis.

RESULTS AND DISCUSSION

Combined analysis of variance over sowing dates and seasons showed significant differences between cultivars for grain yield, biomass, harvest index, grains m^{-2}, spikes m^{-2}, grains spike^{-1}, 1000 grain weight and grain-fill duration (Table 2).

Based on the linear regression of mean grain yield of cultivars (at each sowing date over seasons) on year of release, grain yield has increased from 2523.5 kg ha^{-1} in 1960 to 3294.8 kg ha^{-1} in 1990. This relationship was described by the following linear regression equation:

$$y = 2523.9 + 25.711x, \ (R^2 = 0.30, P<0.01)$$

Where:

y = grain yield (kg ha^{-1}), x = year of release, starting from 1960, R^2 = coefficient of determination (r= 0.55).

The average rate of increase in yield potential (estimated from the slope of the regression line in Fig. 1) was 25.7 kg ha^{-1} $year^{-1}$ over the 30 year period from 1960 to 1990. Under favorable environments, higher rates of yield increase were reported by Waddington *et al.* (1986) and Sayre *et al.* (1997). In contrast to favorable environments, Slafer *et al.* (1994) indicated that yield increases are more difficult to achieve in stress environments. In Sudan, wheat is generally grown in heat stressed environments. Nonetheless, this study indicates that the rate of increase in grain yield obtained in Sudan is comparable to reported rates in a number of studies (Austin *et al.*, 1980; Hucl and Baker, 1987; Slafer and Andrade, 1989).

In addition to grain yield, year of release was positively correlated with 1000-grain weight (r= 0.76, P< 0.01), harvest index (r= 0.53, P<0.01) and grain-fill duration (r= 0.50, P<0.05), but negative correlation was observed with days-to-flowering (r= -0.47, P<0.01) as shown in Fig. 2.

Regressing 1000-grain weight against year-of-release showed an increase of 0.19 grams $year^{-1}$. A similar trend has been reported by Austin *et al.* (1980, 1989) and Cox *et al.* (1988). However, other investigators did not find any significant relationship between 1000-grain weight and year-of-release (Sayre *et al.*, 1997; Siddique *et al.*, 1989a; Slafer and Andrade, 1989; Waddington *et al.*, 1986). In Sudan, the positive and highly significant relationship between 1000-grain weight and year-of-release could be attributed to an emphasis given for selection at this trait.

Harvest index increased by a rate of 0.24% $year^{-1}$. This result is in agreement with most studies where it was observed that increases in grain yield were generally associated with increased harvest index (Austin *et al.*, 1980; Sayre *et al.*, 1997; Slafer and Andrade, 1989). An increase of 0.19 day $year^{-1}$ in grain-fill duration was found. Similar results were reported by Loss *et al.*1989 and Siddique *et al.* 1989b. For days-to-flowering, a decrease of 0.21 day $year^{-1}$ was found. Cox *et al.* (1988), Loss *et al.* (1989) and Siddique *et al.* (1989b) reported similar results, where more modern cultivars reach anthesis earlier than the old ones.

CONCLUSIONS

Due to the high correlation between harvest index and grain yield, further increases in harvest index are expected to increase grain yield above the current level. Many investigators (e.g., Sayre *et al.*, 1997) also suggested that harvest index could be used as a selection criterion for further improvement in grain yield. However, the improvement in harvest index should be done without negatively affecting the present biomass level of the modern cultivars.

Although number of grains m^{-2} and biomass exhibited highly significant correlation with grain yield (r = 0.82 and r = 0.79, respectively), no relationship was found between these traits and year-of-release. Therefore, more emphasis should be given to these traits in future for further grain yield improvement.

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Table 1. Name, origin, year of release and cross of the wheat genotypes used in the study.

Genotype	Origin	Year of release	Cross
Beladi	Local	1960[a]	Historic cultivar
Falchetto	Italy	1968	Falcone/Lauro Bassi
Giza 155	Egypt	1971	Meda Cadet/Hindi 62//Regent/3/*2 Giza 139
Mexicani	Mexico	1972	Lerma Rojo/Norin 10-Brevor//3* Andes Enano
Condor	Australia	1978	Penjamo 60/4* Gabo 56//Tenzanos Pintos Precoz/ Nainari 60 /4/2* Lerma Rojo//Norin 10/Brevor (seln 14)/3/3* Andes
Debeira	India	1982	Hybrid Delhi 160/5/Tobari/Ciano/23854/3/Nainari 60// Titmouse/Sonora 64/4/Lerma Rojo/Sonora 64
El Nielain	Mexico	1990	S948.A1/7* Santa Elena

[a] Estimated date of cultivar Baladi.

Table 2. Means of grain yield and some agronomic traits of seven bread wheat genotypes evaluated for two seasons (1997/98 and 1998/99) at Gezira Research Farm, Wad Medani, Sudan.

Genotype	Grain yield[§] (kg ha^{-1})	Biomass (kg ha^{-1})	Harvest index (%)	Grain m^{-2} (No.)	Spikes m^{-2} (No.)	Grains spike^{-1} (No.)	1000-grain (g)	Grain-fill duration (days)
Beladi	2422f	7678ab	31.2e	8997bc	545bc	40c	27.5de	32.1ef
Falchetto	2809bcde	7644ab	36.6cd	9394bc	464g	44b	30.6bc	33.4cd
Giza 155	2556ef	7869ab	32.4e	9394bc	539bcd	38c	28.9cd	33.7c
Mexicani	3134a	7522b	41.8ab	10691a	567b	39c	30.1bc	33.3cd
Condor	3106ab	7422b	42.2a	10024ab	612a	37c	31.9ab	35.5b
Debeira	2984abc	8063ab	36.9cd	9780ab	515cde	43b	31.1bc	32.5de
El Nielain	3247a	8319a	39.0bc	9833ab	509def	46b	34.0a	39.9a
Mean	2894	7788	37.2	9730	536	41	30.6	34.3
C.V.(%)	12.6	10.9	7.3	13.3	6.3	7.0	9.1	4.7

[§] Numbers followed by the same letter(s) in the same column are not significantly different at the probability level of 0.05 according to Tukey's test.

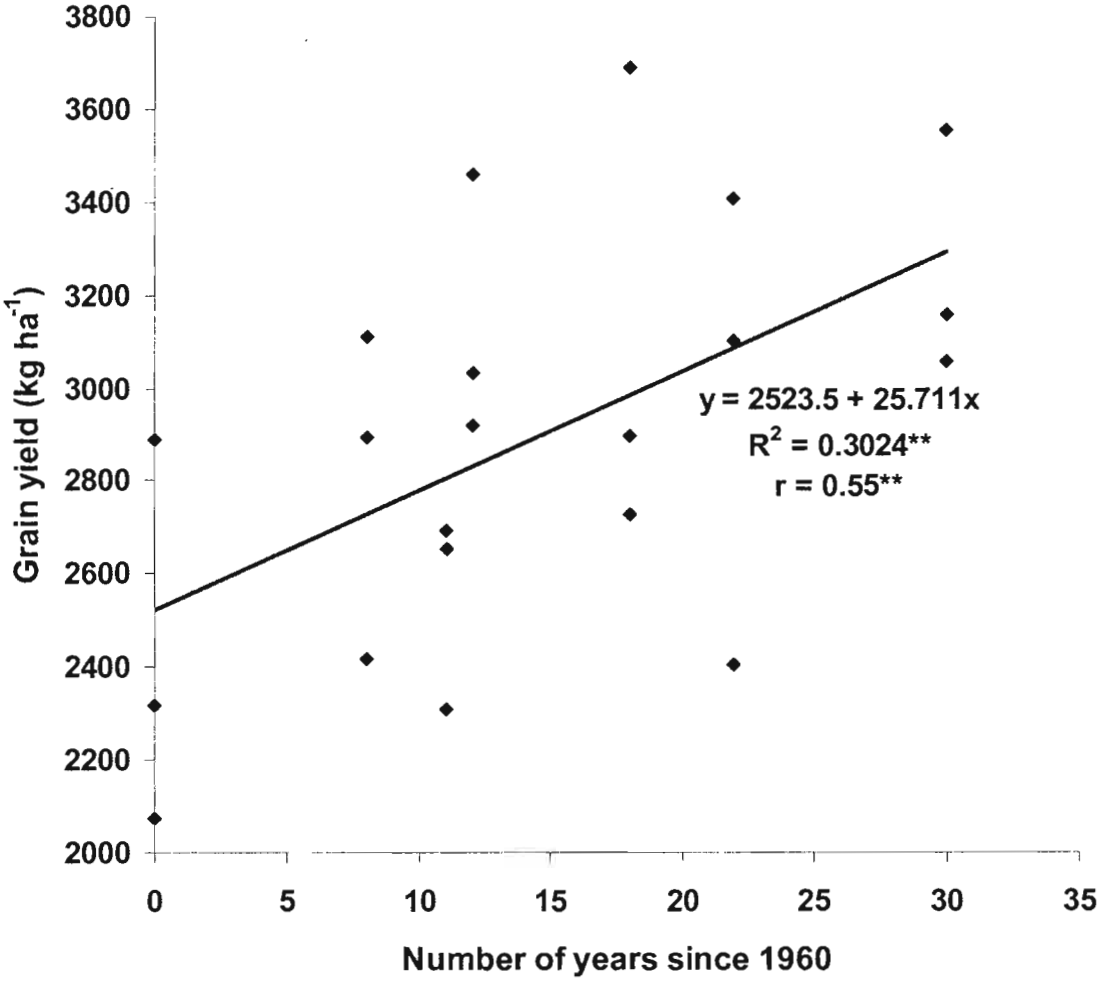

Figure 1. Relationship between grain yield and year of release of seven bread wheat cultivars grown in three sowing dates for two seasons 1997/98 and 1998/99

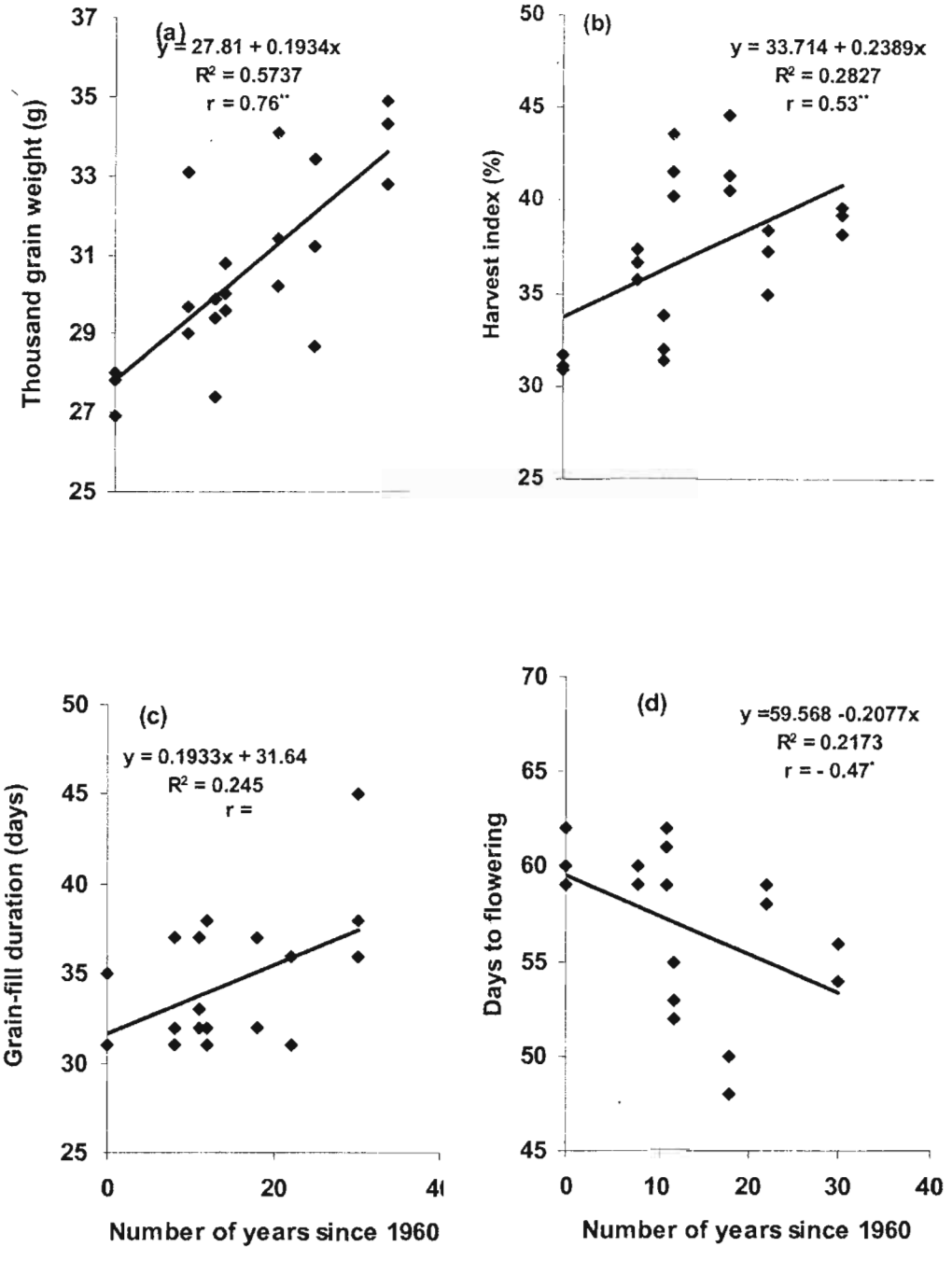

Figure 2. Relationship between year of release of seven bread wheat cultivars and (a) thousand grain weight, (b) harvest index, (c) grain-fill duration and (d) days to flowering.

INCREASING YIELD POTENTIAL FOR MARGINAL AREAS BY EXPLORING GENETIC RESOURCES COLLECTIONS

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ABSTRACT

Global demand for wheat is growing at approximately 2% per year - twice the current rate of gain in genetic yield potential. While increases in yield potential to date have resulted mostly from manipulation of a few major genes (e.g., *Rht, Ppd, Vrn*), the manipulation of these genes has mostly benefited favorable environments, with much lower gains recorded in marginal areas. In the future, exploitation of novel traits found in genetic resources stored in gene banks may be needed to improve yield potential in marginal areas. Lines from landrace collections have been identified as having very high chlorophyll concentrations which may increase photosynthetic capacity. High chlorophyll concentration and high stomatal conductance, which promotes leaf cooling, are associated with heat tolerance. Recent studies have identified high expression of these traits in bank accessions, and both traits were heritable under heat stress. Searches are underway for drought tolerance traits related to remobilization of stem fructans, awn photosynthesis, osmotic adjustment, peduncle length, and pubescence. Potential exists for identifying quantitative traits using QTL analysis in delayed backcross generations. Once markers linked to traits of interest are identified, they could be used to rapidly screen germplasm collections for unique alleles at these markers.

INTRODUCTION

World demand for wheat is growing at approximately 2% per year (Rosengrant *et al.*, 1995), while genetic gains in yield potential of irrigated wheat stand at less than 1% (Sayre *et al.*, 1997). Thus global demand for wheat is growing at about twice the current rate of gain in genetic yield potential, with progress in rainfed environments being even lower. Meeting expected demands by continued expansion of agricultural production into remaining natural ecosystems is environmentally unacceptable, and the economic costs of increasing yields by intensification of agronomic infrastructure are high. Hence a cost-effective and environmentally sound means of meeting global demand is through genetic improvement of the wheat crop. Increases in wheat yield potential to date have resulted mostly from manipulation of a few major genes, such as those affecting height reduction (*Rht*), adaptation to photoperiod (*Ppd*) and vernalizing cold (*Vrn*). Future gains in yield potential, especially under stressed conditions will almost certainly require exploitation of the largely untapped sources of genetic diversity housed in collections of wheat landraces and wild relatives. Little use has been made of them for physiological improvement, even though many traits have been reported to have potential to enhance yield.

Genetic resources

The genetic resources available for plant physiologists and breeders are found in the several *Triticeae* gene pools. The concept of the gene pool was first proposed in 1971 by Harlan and deWet (Harlan, 1992), who suggested the circular way of demonstrating the relationships among gene pools. The primary gene pool consists of the biological species, including cultivated, wild and weedy forms of a crop species; gene transfer in the primary gene pool is considered easy. The secondary gene pool consists of the coenospecies from which gene transfer is possible but difficult. The tertiary gene pool is composed of related genera of annual and perennial grasses from which gene transfer is very difficult and can only be exploited through use of special techniques.

Genetic resources of a cultivated plant species have been categorized by Frankel (1977) and the FAO Commission on Plant Genetic Resources (FAO, 1983), though this categorization is not followed by all centers involved in genetic resource conservation and utilization. These categories are:

- Modern cultivars in current use;
- Obsolete cultivars, often the elite cultivars of the past, many found in the pedigrees of modern cultivars;
- Landraces;
- Wild relatives of crop species in the Triticeae tribe;
- Genetic and cytogenetic stocks; and
- Breeding lines.

In the CIMMYT Wheat Collection, the classification has basically followed the categories as outlined by Frankel and the FAO Commission on PGR (Skovmand *et al.*, 1992). Recently, however, a list with 21 categories was defined in the GRIP project (Skovmand *et al.*, 2000b) to describe the biological status of materials in the collection and other genetic resources. When such specific categories are applied to collections, the efficiency of utilization is enhanced, which makes it easier for users to know exactly what they are working with.

The circles proposed by Harlan and deWet (Harlan, 1992) to describe the gene pools have been very useful, and the concept has provided a rational basis for comparative taxonomies. However, it gives the appearance that separations among the pools are clear-cut, with distinct divisions between one pool and another, though Harlan (1992) states that the line of demarcation may be fuzzy. Further, the circles do not reflect the relative difficulty of utilizing the different gene pools, nor the relative cost of utilizing genetic resources within a gene pool or within a species. Figure 1 presents a schematic diagram of the effort to transfer traits from genetic resources to farmers' fields (Skovmand *et al.*, 2000c). Within the primary gene pool, when moving to closely related species, the cost of utilization increases. And again within a species there are levels of genetic resources, from current high yielding cultivars to landraces, that determine the cost of using these different genetic resources. Moving away from the primary gene pool increases geometrically the effort required to utilize genetic resources such as those in the secondary and tertiary gene pools. This is the reason that it is difficult to release a commercially acceptable cultivar if it does not have prior released cultivars in its pedigree (Rajaram, pers. comm.), i.e., crosses with the secondary and tertiary gene pools tend to disunite favorable gene complexes and thus affect performance. Technology extends the gene pools and decreases the cost, as, for example, embryo rescue has done in the recent past. Also, species found in the secondary gene pool, such as *Aegilops tauschii*, can be used as readily as species in the primary gene pool through the production of hexaploid synthetic

wheats using embryo rescue, followed by chromosome doubling using colchicine (Mujeeb-Kazi, 1995).

Access to genetic resources

Key to the access to wheat genetic resources is the development of a database, or interconnected systems of databases, with the capacity to manage and integrate all wheat information, including passport, characterization and evaluation data. In the early 1990s, CIMMYT's Wheat Program established just such a strategy for integrating and managing all data pertaining to germplasm regardless of where they were generated (Skovmand *et al.*, 1998). The goal was to facilitate the unambiguous identification of wheat genetic resources and remove barriers to handling and accessing information. As a result, the International Wheat Information System (IWIS), a system that seamlessly joins conservation, utilization, and exchange of genetic material, came into being. The system is fast, user-friendly, and is available on an annually updated CD-ROM (Skovmand *et al.*, 2000a). The development of IWIS by the CIMMYT Wheat Program has led to an international effort to develop the International Crop Information System (ICIS) which using IWIS as the model, has made the system more generic to be applicable to different crops (Skovmand *et al.*, 1998).

IWIS has two major components: the Wheat Pedigree Management System, which assigns and maintains unique wheat identifiers and genealogies, and the Wheat Data Management System, which manages performance information and data on known genes. Another information tool, the Genetic Resource Information Package (GRIP), has been developed using IWIS as data warehousing; GRIP, as one of its functions, attempts to collate passport information across gene banks to identify duplications and unique genetic resources (Skovmand *et al.*, 2000b).

Who owns it (genetic resources)?

During the 1980s there was an increasing trend towards a greater application of intellectual property protection (IPP) which contrasted with the 1960s and 70s where IPP on an international level of plant improvement was seen as a detriment to progress. The view that strong IPP could help in maintaining technological leadership has gained respectability, especially in the United States (Siebeck, 1994). Several international initiatives have resulted, among these the 1991 strengthening of the UPOV Convention, which narrowed the breeder's privilege to use protected cultivars as parents in breeding. However, according to Siebeck (1994), the most significant initiative were instigated as part of the Multilateral Trade Negotiating Round in the General Agreement on Tariffs and Trade which ended in 1993. At the insistence of the industrial nations, strengthening of IPP was included as a key negotiating point. The efforts in UPOV and GATT to widen IPP on inventions and breeding technology were paralleled by efforts to regulate international access to genetic resources.

FAO established the "International Undertaking on Plant Genetic Resources" in 1983 (FAO, 1983), and this Undertaking was an attempt to stop genetic erosion and protect genetic resources. At the outset, the Undertaking subscribed to the rule of free interchange of germplasm, and recognized plant genetic resources as "heritage of mankind". However, later disagreements arose over ownership of genetic resources and in 1989 the idea of compensation was introduced which was again modified in 1991 when FAO adopted a resolution of the common heritage principle but subordinated it to "the sovereignty of states".

Unlike the FAO Undertaking, which was voluntary, the Convention on Biological Diversity (CBD) of 1992 was an internationally ratified treaty among nations. The CBD officially recognizes sovereign control by individual nations over biological diversity and resources on their territories. The convention excludes material collected before December 29, 1993, when the CBD took effect, but any germplasm collected after that date in a country, which has signed the CBD, comes under the provisions of the Convention. One of the results of the discussions on ownership of genetic resources has been the signing of an agreement between the CGIAR and FAO where the germplasm collections held in trust by the CGIAR system were placed under the auspices of FAO.

The result is likely to be that genetic resources will not be freely available to everyone in the future, and are likely to be made available under some type of Intellectual Property Rights (IPR) agreement. For example the accessions in the CIMMYT collection held under the FAO/CIMMYT in trust agreement is shared under a Material Transfer Agreement which states that these accession can be utilized but not protected by any IPR. However, products derived from research and breeding with such material can be protected as they are seen to a different product belonging to the scientist or breeder who developed these[1].

The search for new variability

A classical method of identifying useful new variability is the recognition of potentially useful traits by experienced scientists and research staff. This can occur either during routine maintenance of collections, during special studies or as an offshoot of prebreeding and breeding exercises carried out for other purposes. These phenomena should not be underestimated, as much of the useful novel variation deployed in cultivated crops has been recognized in these ways.

Augmented use of seed multiplication nurseries: Seed multiplication nurseries can be used for the characterization and evaluation of germplasm collections for non-disease and non-destructive traits. Since these routine seed re-generation activities have to be carried out, they can be an inexpensive way of collecting such data. Recent work has indicated (Hede *et al.*, 1999; DeLacy *et al.*, 2000) that traditional agronomic traits, including those of low heritability, measured on small, seed-increase hillplots can be used for such purposes. Curators of germplasm banks have traditionally avoided these traits, which are useful for plant improvement programs. A description of germplasm based on 'useful' attributes is immediately advantageous to practical plant improvement programs by indicating where useful variation may be found in the collection. It can also describe whether adequate collection has been done (covering the range of variation) and indicating where it is to be found for recollecting expeditions.

How to use the identified traits

It has to be recognized that genetic resources with desirable traits as a general rule need to be tested and improved to be of any use in wheat improvement (Figure 2). Most often these genetic resources have many un-desirable characters such as extreme disease susceptibility,

[1] In 2000, CIMMYT adopted a policy on intellectual property right (IPR) which states that, while it adheres to all relevant international laws and treaties concerning IPR and genetic resources, the in-trust agreement signed with the FAO, and the CGIAR's "Ethical Principles Relating to Genetic Resources, it may on occasion seek to protect the products of its research by obtaining IPR through patents, plant breeders' rights, and/or trade secrets to serve the resource poor of the world (CIMMYT, 2000).

low yield and highly specific adaptation to a certain environment, even though they have been identified as having one highly needed trait.

Therefore, the identified germplasm need to enter a prebreeding program before it can be used in improvement work. Figure 2 demonstrates two schemes for prebreeding with different purposes; one is the open parent cyclical crossing program and the other is a backcrossing program to produce isogenic lines. These two programs have different purpose and different end result and the first is progressive while the second is unprogressive in term of yield potential.

The open parent cyclical crossing program described by Rasmusson (2000) is utilized when introgressing a trait known to be of valuable. Rasmusson was striving to introgress characters from two-row barley into six-row barley and found that the initial cross yielded germplasm with no putative candidates for cultivar release, best lines yielding about 20 percent less than the improved parent. The second cycle of the program, where the improved parent was the current cultivar, resulted in progenies which yielded about 98 percent of best parent, while the third cycle, again using the best current cultivar as a parent, yielded 112 to 119 percent of the checks. Through this scheme, the germplasm with the desired trait is produced which could be competitive in a cultivar release program.

The backcrossing program to produce isogenic lines is utilized when the identified trait has not been proven to have value. A recurrent parent is utilized and crossed repeatedly to the genetic resource with the desired trait. In each backcross generation the two extreme tails of the populations are selected; i.e., lines with highest expression of the trait and lines with lowest expression. At the end of this program it is expected that the two sets of lines differ only for the trait in question. Then trials can be conducted to assess the value of the trait.

Future utilization of genetic resources

As evidenced by the above, genetic resources have played a significant role in wheat improvement and will continue to do so by providing breeders with the variability they require for future improvements. Variability will be needed 1) to further increase wheat's yield potential; 2) to provide new sources of disease and pest resistance and maintain the yield levels achieved so far; 3) to develop germplasm adapted to more marginal environments; and 4) to improve quality. To date genetic resources have contributed mostly to provide new sources of disease and pest resistance to maintain yield levels achieved.

Only a few examples of genetic resources contributing to the three other objectives. One of these primary examples is the use of dwarfing genes, especially genes *Rht1* and *Rht2*, that became available through the Japanese wheat Norin 10, which in turn inherited them from Shiro Daruma, a Japanese landrace (Kihara, 1983). The incorporation of these dwarfing genes illustrates the difficulty of using genes from unadapted materials, since persistent efforts were required to transfer them into a genotype of value (Borlaug, 1988; Krull and Borlaug, 1970). It also shows that desirable characteristics other than the apparent ones may result from such germplasm. While incorporating strong straw to avoid lodging, better fertility and tillering capacity were obtained by Krull and Borlaug (1970). It is now obvious that dwarfing genes *Rht1* and *Rht2* have a direct effect on yield over and above the benefits derived from diminished lodging (Gale and Youssefian, 1986).

Table 1 summarizes a survey done by Cox (1991) and from this it is obvious that most introductions to the US were used to improve disease and pest resistance. The only yield related traits listed were reduced height, improved straw, large seed and yield *per se*. No cases for improving yield in marginal environments were listed and only two for improving quality: higher protein and gluten strength.

In another report (Fischer 1996) traits involved in improving yield by introducing characteristics from genetic resources are described. Erect leaf habit was introduced into CIMMYT germplasm from several sources including *T. sphaerococcum* based on the idea that a more erectophile leaf canopy would have higher radiation use efficiency, and a number of lines were developed through a prebreeding program. The germplasm were used in both bread and durum wheat programs and the trait can be found in current materials including the highly successful cultivars 'Bacanora 88', 'Altar 84' and 'Aconchi 89'.

However, in many other cases physiological characteristics that are implied as causal in improving yield potential have only been identified retrospectively. We need to act more proactively by identify traits with the potential to improve yield and evaluating them within the context of ongoing breeding objectives. Reviews of traits that might contribute to future increases in yield potential can be found elsewhere (Reynolds *et al.*, 1999; 2000).

Traits to raise yield under stressed conditions

Wheat yields are reduced by 50-90% of their irrigated potential by drought on at least 60 million ha in the developing world. At CIMMYT, attempts are underway to further improve drought tolerance by introgressing stress adaptive traits into empirically selected drought tolerant germplasm. Our current conceptual model for drought encompasses high expression of the following traits: seed size, coleoptile length, early ground cover, pre-anthesis biomass, stem reserves/remobilization, spike photosynthesis, osmotic adjustment, heat tolerance, leaf anatomical traits (such as glaucousness, pubescence, rolling, thickness), high tiller survival, stay-green, and stomatal conductance, although not all traits would be expected to be useful in all drought environments (Reynolds *et al.*, 1999). CIMMYT's germplasm collection is being screened, as resources allow it, for high expression of many of these traits.

High stomatal conductance permits leaf cooling through evapotranspiration and this, along with higher leaf chlorophyll content and stay-green, is associated with heat tolerance (Reynolds *et al.*, 1994). Recent studies identified high expression of these traits in bank accessions, and both traits showed high levels of heritability under heat stress (Villhelmsen *et al.*, 2000). They are being crossed into good heat tolerant backgrounds.

Pubescence and glaucousness are traits which protect plant organs from excess radiation under stressful conditions (see Loss and Siddique, 1994). Searches are under way for these traits and a number of other leaf traits such as leaf rolling, leaf thickness, and upright posture, which may well play similar roles under stress.

Osmotic adjustment (Blum, 1999) and stored stem fructans (Blum *et al.*, 1998) are traits that have been implicated in stress tolerance. Searches are underway for high expression of these traits among germplasm bank accessions, although laboratory protocols are required for their identification. High spike photosynthesis is another trait that could contribute to yield under stress but which is very time consuming to measure. For traits that are difficult to measure (and/or that show marked genotype by environment interaction), it is logical to develop

genetic markers that can be used to confirm the presence of useful traits more unequivocally than by measuring phenotypic expression.

CONCLUSIONS

Lines have been identified from landrace collections with very high chlorophyll concentration that may increase photosynthetic capacity. High chlorophyll concentration and high stomatal conductance (which permits leaf cooling) are associated with heat tolerance. Recent studies identified high expression of these traits in bank accessions, and both traits were heritable under heat stress. Searches are underway for drought tolerance traits related to remobilization of stem fructans, awn photosynthesis, osmotic adjustment, and pubescence. Seed multiplication nurseries can be used for the characterization and evaluation of germplasm collections for physiological traits. The characterization data can be analyzed using pattern analysis, which can provide a good description of the accessions. The advantage of using these augmented seed nurseries is that cohorts of high(er) yielding lines are identified which can be used directly or examined for 'new' traits. Genetic diversity from wheat's wild relatives has already been exploited through wide-crossing to improve disease resistance. Further potential exists for identifying quantitative traits using QTL analysis in delayed backcross generations. Once markers linked to traits of interest are identified, the possibility exists to rapidly screen the germplasm collections for unique alleles at these markers.

The last 30 years have witnessed an unprecedented level of international wheat germplasm exchange and the development of a greater degree of genetic relatedness amongst successful cultivars globally; the concept of broad adaptation has thus been well vindicated. However, this is seen by some as increasing genetic vulnerability to pathogens, although such vulnerability depends more on similarities in resistance genes, which may actually be more diverse now than before. A recent study (Skovmand and DeLacy, 1999) indicates that over the last 4 decades in the CIMMYT Wheat Program, there has been a steady increase in genetic diversity as measured by pedigree analysis. Various new factors (including the growing strength of national breeding programs in the developing world and the advent of breeders' rights) should result in increased diversity amongst cultivars and perhaps lead to the exploitation of hitherto-overlooked specific adaptation in wheat. This would be especially important if climate change accelerates. Just as increasing nitrogen supply and improving weed control have been almost universal driving factors of wheat cultivation in the last 50 years, higher atmospheric concentrations of CO_2 and global warming with resulting warmer temperatures could significantly influence breeding objectives in the next.

Genetic resources are fundamental to the world's food security and central to efforts to alleviate poverty, contribute to the development of sustainable production systems and supplement the natural resource base. The germplasm conserved is especially rich in wild crop relatives, traditional farmer cultivars and old cultivars, which represent an immense reserve of genetic diversity. The material conserved either *ex-situ or in-situ* is a safeguard against genetic erosion and a source of resistance to biotic and abiotic stresses, improved quality, and yield traits for future crop improvement. As Don Rasmusson (pers. comm.) recently stated "a little genetic diversity goes a long way".

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Table 1. Contributions to germplasm improvement of introduced genetic resources; adapted from Cox, 1991.

Yield potential	Cases	Resistance	Cases	Marginal environment	Cases	Quality	Cases
Reduced height	15	Strawbreaker	2			High protein	2
Yield	6	Powdery mildew	9			Gluten strength	1
Large seed	1	Stripe rust	4				
Stiff straw	1	Leaf rust	12				
		Stem rust	12				
		Septoria leaf blotch	3				
		Bunt	3				
		Soilborne mosaic virus	1				
		Cereal leaf bettle	1				
		Hessian fly	3				
		Snow mold	1				
		Greenbug	1				
		Wheat curl mite	1				

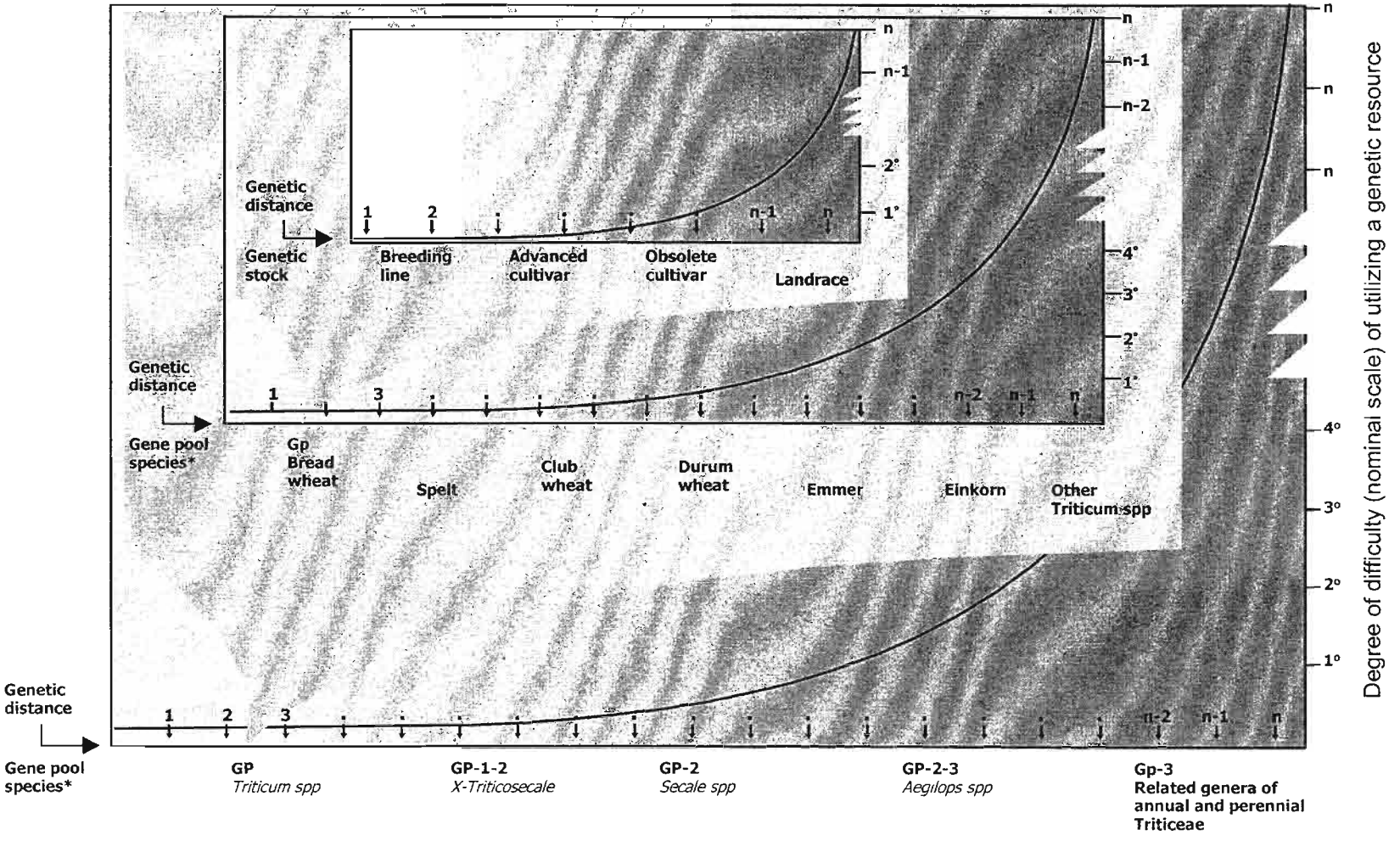

Figure 1. The Triticeae gene pools and the relative difficulty of their utilization.
*** not in strict phylogenetic order**

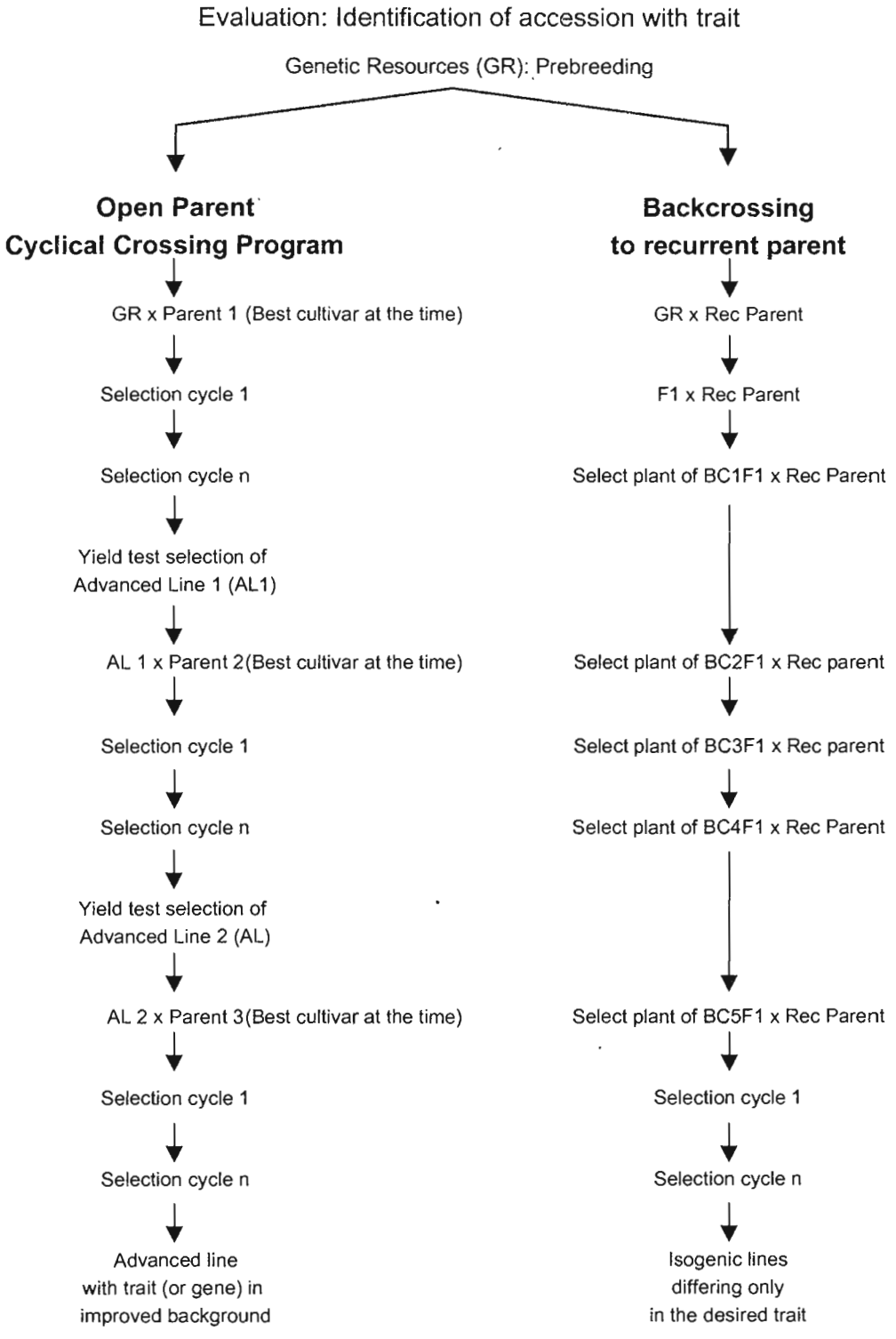

Figure 2. Utilization of genetic resources: Prebreeding schemes.
*** Source: Rasmusson, 2000.**

BREAD WHEAT YIELD STABILITY AND ENVIRONMENTAL CLUSTERING OF MAJOR WHEAT GROWING ZONES IN ETHIOPIA

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ABSTRACT

A replicated yield trial comprising eighteen bread wheat genotypes and two checks was conducted at 14 locations for two consecutive years (1997-1998). The testing locations were evenly distributed across the major wheat growing zones in Ethiopia, and were characterized by various biotic and abiotic stresses. The combined data were subjected to statistical analysis to determine the pattern of adaptation of the test genotypes and to cluster the wheat growing zones on the basis of yield potential and limitations. The results showed that genotypes could be grouped into "widely", "specifically" and "generally" adapted types. Among these, HAR2536 was found to have wide adaptation while HAR 2192 was specifically adapted to high rainfall areas owing to its long duration growth habit. The testing sites were broadly clustered into high yielding and low yielding types within different interactions. The environmental clusters followed altitude classes and rainfall amount and duration. This investigation elucidated that wheat productivity is more affected by moisture amount. Thus, variety selection for different moisture regimes plays an important role to maximize the productivity of rainfed wheat production in Ethiopia.

INTRODUCTION

Wheat (*Triticum aestivum* and *T. turgidium*) is a major cereal grown in Ethiopia (6 - 14^0 N and 35 – 42^0 E; 1500 - 3200 m a.s.l.) (Hailu, 1991). It grows in the highlands of southeastern, central and northwestern agro-ecological zones. Varieties have different responses across environments and years resulting in significant genotype environment interaction. Phoelman and Slepper (1966) indicated that yield is a complex factor that is affected by genotype, environment and genotype x environment interaction. Denis and Vincourt (1982) showed that genotypes and environments can be clustered by giving the corresponding value of the removed sum of squares for interactions. The purpose of this study was to measure yield performance stability and cluster wheat growing environments.

MATERIALS AND METHODS

The experiment was carried out at 14 locations representing major wheat growing areas of Ethiopia for two consecutive years, 1997-1998. Eighteen bread wheat genotypes with two checks were tested in an RCBD design with four replications. Each entry was grown in plots of six rows with inter-row spacing of 0.2 m and 2.5m length (3 m^2). Seeds were drilled manually into rows at a rate of 150 kg ha^{-1}. Recommended fertilizer rates were applied at each site. Recommended agronomic practices were applied to the crop. Data on agronomic

parameters and disease were taken at the appropriate stage of the crop. The four central rows were harvested and the yield was converted to t ha^{-1}.

RESULTS AND DISCUSSION

Grain yield varied significantly among the tested lines and across locations (Table 1). Stability and cluster analyses of the twenty bread wheat genotypes were evaluated for twenty-eight locations. Variety by location interaction was significant showing change in relative yield performance and the genotypes environments. The results showed that the genotypes could be grouped into widely, specifically and generally adapted types (Tables 1 and 3). Among the twenty varieties K6290-Bulk/CHIL was found to have wide adaptation while Dashen/HAR722, HAR2552, HAR2527, HAR2522, HAR2561 and HAR2524 were found to have a general adaptation. Additionally, HAR2354 and HAR2536 were shown to be suitable for favorable environments while HAR2140, HAR2145 and HAR2534 for that of less favorable areas (Table 3). The testing sites were broadly clustered into high yielding and low yield zones. The environmental clusters generally followed altitude classes and yield potentials of the growing locations (Tables 4 to 8).

CONCLUSIONS AND RECOMMENDATIONS

The following recommendations could be made:

- K6290-Bulk across the locations;
- Dashen/HAR722, HAR2561 and HAR2524 for generally adapted environments;
- HAR2354 and HAR2536 for favorable environments; and
- HAR2534, HAR2140 and HAR2145 for less favorable environments.

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Table 1. Combined analysis of variance for grain yield of 20 bread wheat genotypes grown at 28 locations (1997-1998).

Source	df	MS
Genotype	19	4344459.8**
Locations	27	164540741.3**
Reps within Env.	84	6036557.4
Genotype x Loc.	513	871059.9**
Error	1596	815216850.000
C.V.(%)	21.19%	

Table 2. Pedigrees of the 20 bread wheat genotypes grown at 28 locations (1997-1998).

Variety	Pedigrees
HAR1685	ND/G9144//KAL//BB/3/YACO/4/VEE
HAR2140	GOV/AZ//MSU/3/DODO/4/BOW
Dashen/HAR722	DASHEN/HAR722
HAR2195	ATTILA
K6290-Bulk/CHIL	K6290-BULK/CHIL
HAR2527	ATTILA
HAR2145	WEAVER
HAR2169	ROEK/KAUZ
HAR2538	BOW/PVN
HAR2522	TINAMOU
HAR2192	MILAN
HAR2552	TINAMOU
HAR2354	SERI*2//GTA/DUR69
HAR2562	CATBIRD
HAR2561	PRINIA
HAR2519	SW 89-3243
HAR2524	ATTILA
HAR2534	NDVG9144//ICAL/BB/3/YACO/4/CHIL
HAR2536	PRINIA
PAVON-76	VCM//CNO/7C/3/KAL/BB

Table 3. Mean grain yield and estimates of stability parameters for bread wheat national variety trial conducted at 28 environments (1997-1998)

Entry	Variety	Grain Yield (kg/ha)	Stability parameters		
			b	Sd^2	R^2
1	HAR1685	3751	1.051	86804.905*	0.893**
2	HAR2140	3175	0.985	0.0	0.922**
3	Dashen/HAR722	3633	1.023	0.0	0.925**
4	HAR2195	3363	1.071*	0.0	0.951**
5	K6290-Bulk/CHIL	3708	0.992	0.0	0.916**
6	HAR2527	3243	1.060	0.0	0.940**
7	HAR2145	3095	0.916	0.0	0.904**
8	HAR2169	3159	1.006	74740.260*	0.888**
9	HAR2538	3370	0.905**	0.0	0.930**
10	HAR2522	3320	1.018	0.0	0.970**
11	HAR2192	3200	0.877	98296.219*	0.848**
12	HAR2552	3364	1.005	0.0	0.950**
13	HAR2354	3631	1.146**	4331.729*	0.933**
14	HAR2562	3341	1.043	92041.487*	0.889**
15	HAR2561	3411	1.076	0.0	0.946**
16	HAR2519	3059	0.850	99864.567*	0.839**
17	HAR2524	3437	1.036	0.0	0.922**
18	HAR2534	3267	0.992	0.0	0.962**
19	HAR2536	3484	1.039	81723.738*	0.892**
20	PAVON-76	3457	0.909	209116.72*	0.813**

b = coefficient of regression.
Sd^2 = deviation from regression.
r^2 = coefficient of determination.

Table 4. Environment dendrogram using average linkage (between groups) and rescaled distance cluster combined.

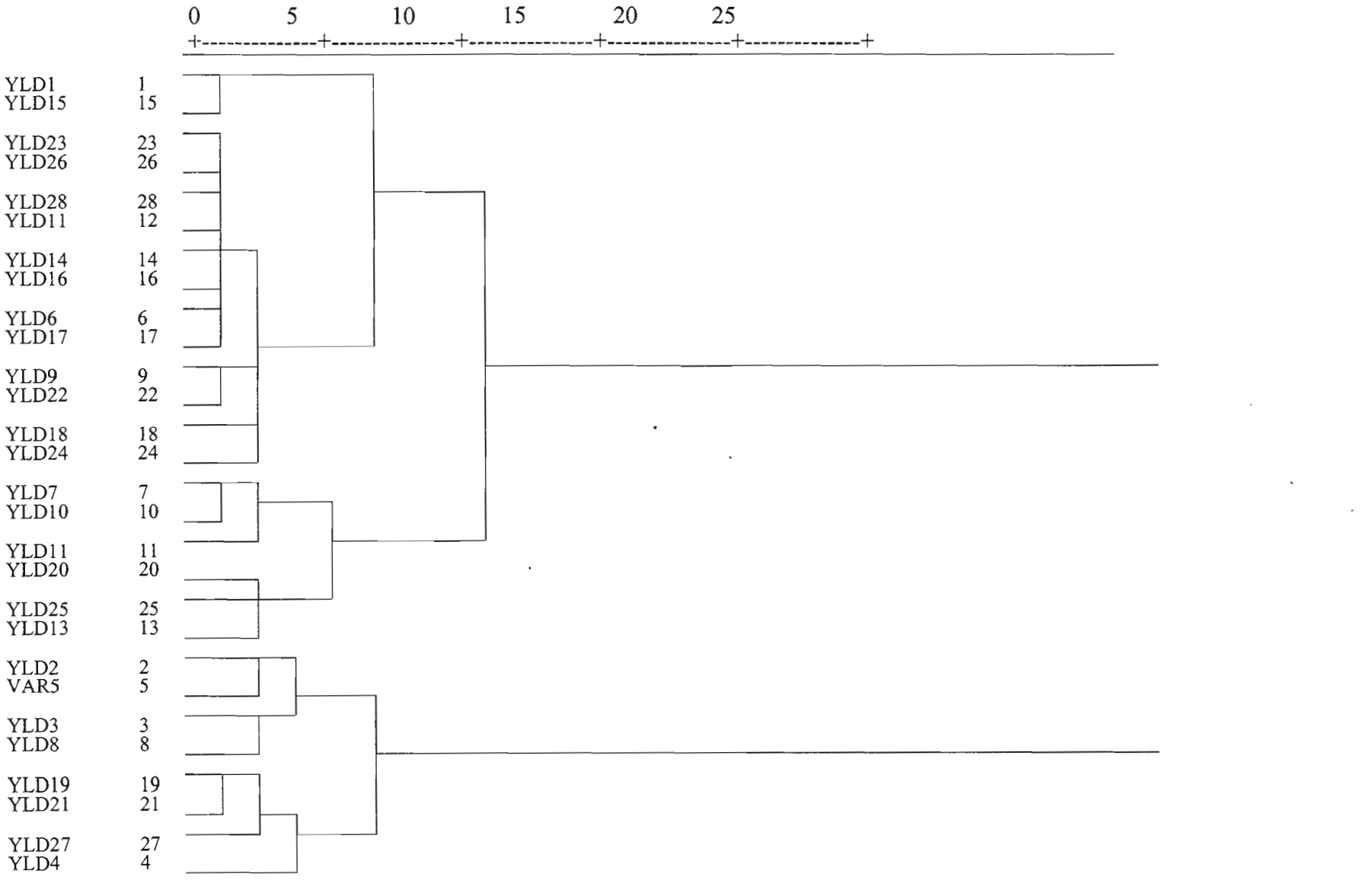

Table 5. Description of environment dendrogram.

No.	Code	Environment	Year
1	YLD1	Dhera	1997
2	YLD2	Kulumsa	1997
3	YLD3	Bekoji	1997
4	YLD4	A.Robe	1997
5	YLD5	A.Negele	1997
6	YLD6	Asasa	1997
7	YLD7	Adet	1997
8	YLD8	Holetta	1997
9	YLD9	Ginchi	1997
10	YLD10	D/Zeit	1997
11	YLD11	Alemaya	1997
12	YLD12	Kokate	1997
13	YLD13	Sinana	1997
14	YLD14	Hosaina	1997
15	YLD15	Dhera	1998
16	YLD16	Kulumsa	1998
17	YLD17	Bekoji	1998
18	YLD18	A.Robe	1998
19	YLD19	A.Negele	1998
20	YLD20	Asasa	1998
21	YLD21	Adet	1998
22	YLD22	Holetta	1998
23	YLD23	Ginchi	1998
24	YLD24	D/Zeit	1998
25	YLD25	Alemaya	1998
26	YLD26	Kokate	1998
27	YLD27	Sinana	1998
28	YLD28	Hosaina	1998

Table 6. Dendrogram of varieties using average linkage (between groups).

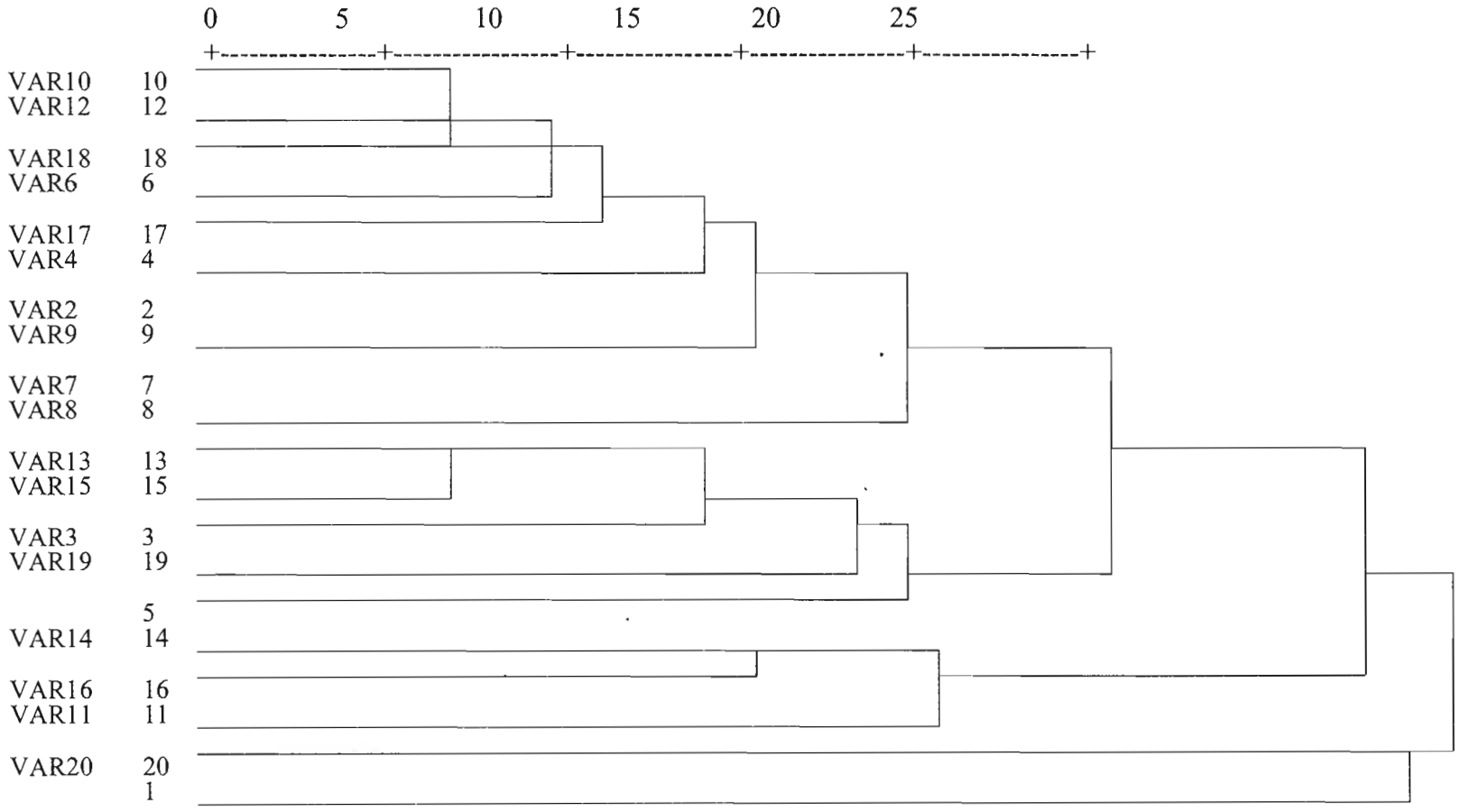

Table 7. Description of variety dendrogram.

No.	Code	Variety
1	VAR1	HAR1685
2	VAR2	HAR2140
3	VAR3	Dashen/HAR 722
4	VAR4	HAR2195
5	VAR5	K6290-Bulk/Chil
6	VAR6	HAR2527
7	VAR7	HAR2145
8	VAR8	HAR2169
9	VAR9	HAR2538
10	VAR10	HAR2522
11	VAR11	HAR2192
12	VAR12	HAR2552
13	VAR13	HAR2354
14	VAR14	HAR2562
15	VAR15	HAR2561
16	VAR16	HAR2519
17	VAR17	HAR2524
18	VAR18	HAR2534
19	VAR19	HAR2536
20	VAR20	PAVON-76

Table 8. Grain yield of 20 bread wheat varieties (q/ha) grown in 28 environments.

Entry	Variety	Locations													
		Dhr	**Kul**	**Bek**	**A.Robe**	**A.Neg**	**Asa**	**Adet**	**Hol**	**Gin**	**D/Z**	**AUA**	**Kok**	**Sin**	**HOs**
1	HAR1685	1383	4140	3680	4932	5029	3420	5165	4635	2582	3615	4404	2256	5265	2004
2	HAR2140	1030	3172	3284	4006	5142	2677	4019	3828	2394	2758	3431	1942	4640	2132
3	Dashen/HAR722	1316	3890	3804	4858	5567	3403	4912	4390	2373	2640	4000	2323	4990	2403
4	HAR2195	1352	3846	3037	4128	5631	3039	4502	3612	2355	2845	3403	1934	5260	2142
5	K6290-Bulk/Chil	1164	3964	3664	4975	5313	3282	4716	3634	3134	3539	4285	2350	5479	2419
6	HAR2527	1191	3428	2661	3995	5417	2752	4879	3723	2172	2682	3899	1778	4672	2158
7	HAR2145	1189	3071	3241	3738	4962	2553	4535	3936	2329	2181	3698	1917	3770	2211
8	HAR2169	1132	3195	3350	4123	4976	2788	5077	3679	2175	2795	2496	1943	4233	2273
9	HAR2538	1159	3493	4004	3945	4733	2983	4640	4113	2359	2762	4028	2179	4496	2295
10	HAR2522	971	3296	3419	4125	5159	3300	4380	3787	2411	2802	3923	1971	4610	2332
11	HAR2192	1146	2998	3383	3616	4438	3091	4290	4370	2311	2617	3200	1985	5236	2127
12	HAR2552	1208	3404	3564	4047	5298	3217	4237	4405	2305	2960	3697	2179	4538	2046
13	HAR2354	1272	3932	3700	4652	5996	3489	5067	3793	2005	3299	3649	2056	5579	2350
14	HAR2562	1068	3466	2426	4341	5569	3419	4606	3816	2220	3242	3713	1787	5178	1932
15	HAR2561	1222	3687	3567	4586	5432	3103	4438	3685	2187	2910	3693	1975	5345	1932
16	HAR2519	1279	2925	2667	3252	5069	3523	3929	3436	2011	3079	3384	1796	4365	2113
17	HAR2524	1319	3578	3012	4109	5395	3512	4902	3566	2132	3108	4340	2231	4582	2335
18	HAR2534	1325	3260	3348	4046	5420	2778	4359	3888	2209	2518	4045	1901	4689	1954
19	HAR2536	1375	3920	3537	4653	5878	3917	4206	3336	2533	2515	3523	1882	5415	2085
20	PAVON-76	1254	3889	3476	2908	5584	3033	4854	3786	2346	3867	3864	2202	5085	2260
	Location mean	1217	3527	3341	4152	5300	3164	4585	3871	2327	2937	3734	2029	4871	2175
	Grand mean														

MILLING AND BAKING QUALITY OF ETHIOPIAN BREAD WHEAT CULTIVARS

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ABSTRACT

Information on physical and chemical quality parameters are necessary to assess the suitability of wheat varieties for different industrial uses. During 1998, ten recommended bread wheat varieties were tested with and without fertilizer at three locations in Arsi Zone of Ethiopia, representing well-drained highland and medium altitude sites and a waterlogged Vertisol. The varieties were subjected to laboratory analysis for milling and baking quality parameters, viz., FLY, FPC, MDT, LFV, HLM and TKM. Statistically significant differences were observed among the varieties for all characters studied. There were also significant differences due to applied fertilizer for flour yield, test weight, kernel weight and grain yield. Fertilizer by variety interaction significantly affected only flour protein content. Flour protein content was highly and positively correlated with test weight, grain size, flour yield and dough development time. Flour yield was positively correlated with test weight and grain size. Varieties such as Dashen, Galama, Megal and Abola exhibited good baking quality due to high quality gluten and high water absorption capacity. The other test varieties tended to be more suitable for biscuit making.

INTRODUCTION

Wheat quality is usually defined in terms of suitability. The quality of hard red winter and spring wheat is defined in terms of specific properties that determines suitability for hard wheat milling and bread production (Finney *et al.*, 1987). Thus, quality of any kind of wheat can not be expressed in terms of a single property, but depends on several milling, chemical, baking, processing and physical dough characteristics, each important in the production of bread, pastry and pasta products.

Milling and baking qualities of bread wheat depend upon variety, environment, fertilizer treatment and post-harvest conditions (Finney *et al.*, 1987; Nair *et al.*, 1990; Stewart, 1984). The same authors suggested that good milling quality should consider endosperm texture, high flour yield and good flour color. Suitable protein quality, adequate protein quantity, high water absorption and low cereal α-amylase activity are all considered as important criteria for good bread flour. Wheat whose endosperm, when crushed, breaks down along the outlines of endosperm cells in to easily sifted particles is considered as 'hard' wheat. On the other hand, wheat whose endosperm splits in an apparently haphazard manner to produce a mass of fine cell debris with poor flow properties is classified as 'soft' wheat. The difference appears to be of genetic origin. It can only be modified, to a small extent, by environment and fertilizer

treatment (Stewart, 1984).

Other things being equal, milling industries prefer 'hard' wheat type. However, the final preference depends upon the end-use product. That is, bread bakers prefer flour from 'hard' wheat while biscuit manufacturers demand flour from 'soft' wheat. One of the reasons for the difference lies on water absorption capacity of the two categories, which in turn is a manifestation of protein quality and quantity. The other reason is that more flour is extracted from hard wheat than from soft wheat. This additional flour is derived from the layer of endosperm adjacent to the bran and is higher in protein content than the remainder of the endosperm, and the protein loss during milling is less with 'hard' than with 'soft' wheat (Stewart, 1984).

The quality and quantity of protein can affect the baking quality of wheat flour. Dough made from wheat flour possesses elastic properties due to the formation of gluten, the hydrated form of the water insoluble protein. Wheat is the only cereal whose proteins exhibit this property, and thus, is unique in its baking behavior (Stewart, 1984). Wheat varieties that produce dough with high elastic properties produce good bread, provided that the protein is present in sufficient quantity and the initial wheat was in a good condition. Such types of wheat are known as 'strong' wheat. On the contrary, varieties which give rise to dough which is non-elastic but very extensible (not desirable for bread making but considered good for biscuit production) are categorized under 'weak' wheat (Stewart, 1984; Williams *et al.*, 1986).

In Ethiopia, wheat has been one of the major cereals of choice, dominating the food habit and dietary practices and known to be a major source of energy and protein for the highland population (Abera, 1991). The wheat improvement research since its inception prior to 1930's (Hailu, 1991), has focussed on improving grain yield and disease resistance. With the emerging agro-industries using wheat as a raw material, industrial quality of wheat has become important. Because of low wheat supply and low quality row materials, some of these agro-industries are importing wheat (particularly durum wheat) from overseas.

Quality reports are available on few of the wheat varieties released so far. However, the industrial quality status of all commercial wheat varieties needs to be documented. The aim of this study, therefore, was to determine the quality attributes of some commercial bread wheat varieties, classify them based on their intended uses and make the information available to the end users.

MATERIALS AND METHODS

This study was conducted in 1998 at three different locations representing different environments. Bekoji (2750 m a.s.l.) represented high altitude and high rainfall area. Kulumsa (2150 m a.s.l.) represented medium altitude and moderate rainfall environment. Arsi-Robe (2400 m a.s.l.) represented high rainfall and waterlogged highland Vertisol areas. Ten commercial bread wheat varieties were planted on June 18, July 15 and July 16 at Bekoji, Arsi-Robe and Kulumsa, respectively. The experimental design was a split-plot design with fertilizer levels as main plot and varieties as sub-plot treatments. Three replications were used. Each variety was established on six rows each 2.5 m and separated by 20 cm. The seeds were drilled by hand at a rate of 150 kg/ha.

Fertilizer levels included F_0 = No fertilizer application and F_1 = 60-69 kg ha^{-1} N-P_2O_5-for

Bekoji and Arsi-Robe and 60-60 kg ha^{-1} N-P_2O_5 for Kulumsa. F_1 fertilizer levels were based on recommendations for the respective locations. Urea and DAP were the sources for N and P, respectively. N was split applied (50% at planting and 50% at tillering). The ten test varieties and their descriptions are shown in Table 1.

Laboratory analysis of seven quality parameters, as described in Table 2, was carried out at the Small Grains Institute in the Republic of South Africa. Preliminary quality observation (non-replicated) was conducted on the same varieties in the preceding year and the result is presented in Table 6 for comparison. Analysis of data was performed by AGROBASE software. Means were compared based on least significant difference (LSD). Quality parameters were correlated against each other using simple linear correlation method.

RESULTS AND DISCUSSION

The combined analysis of variance indicated that location effect caused significant differences among the varieties in all characters measured (Table 3). The performance of the varieties with respect to FLY, HLM, TKM, MDT and GY is significantly different across the locations. FPC, FLY, HLM, TKM and GY of the varieties differed significantly due to fertility conditions. The applied fertilizer did not cause significant differences in flour protein content of a given variety in this trial. But the interaction of fertilizer by variety caused significant differences in FPC of the varieties. This finding seems to go in line with the fact that grain protein quality and quantity may increase, decrease, or not respond appreciably to N-fertilizer applied depending on genotype, existing available soil N supplies, environmental stresses, type of fertilizer (ammonia, urea, nitrate, or other form), and time and method of application. (Bates *et al.*, 1980; Stewart, 1984).

At Kulumsa, the varieties showed significant difference (p 0.1%) in all parameters while fertilizer application caused significant difference only in GY, TKM and MDT (Table 3). At Bekoji, fertilizer application did not show significant effect in all parameters with the exception of GY. At Arsi Robe, the effect of fertilizer was highly significant in all parameters except in MDT. The interaction of fertilizer by variety caused no significant difference in parameters considered at Kulumsa location. The same trend was observed among the varieties at Bekoji except for MDT. At Arsi Robe, the interaction of fertilizer by variety was highly significant for TKW, FLY, FPC, MDT and LFV but non-significant for GY and HLM.

Physical Qualities

The results of the physical characteristics of the varieties are shown in Table 4. With fertilizer application, the top grain yielder at Kulumsa was Mitike with 7839 kg/ha and is significantly different from the rest of the entries. The next best yielders were Galama, K6295-4A, Pavon-76, Abola and Kubsa with 6549, 6522, 6307 and 5508 kg/ha, respectively, and the differences were not significant. Yields at Bekoji and Arsi Robe were highly irregular due to severe disease incidence at both locations and waterlogging at Arsi Robe.

HLM results were higher at Kulumsa and Arsi Robe and relatively lower at Bekoji. Abola, ET-13A_2, K6295-4A, Megal and Mitike had mean HLM of 80 kg/hl or higher as shown in Table 4. Varieties showed higher HLM with fertilizer application. The mean TKM was 30.0, 28.9 and 26.1 grams for Arsi Robe Kulumsa and Bekoji, respectively. The varieties Dashen, ET-13A_2, K6295-4A, Megal and Mitike had relatively higher TKM compared to the rest of the varieties. Fertilizer application slightly improved TKM performance of the varieties

(28.87 vs. 27.72).

Chemical Qualities

As shown in Table 3, at all the three testing locations, the varieties differ significantly in their FLY. Fertilizer application caused significant difference in FLY of the varieties only at Arsi Robe but not at Kulumsa and Bekoji, while the interaction of the two was found significant at Bekoji and Arsi Robe. The overall FLY of the varieties was lower (48.0% to 58.4%) due to severe disease incidence. Relatively highest FLY was found at Kulumsa while lowest FLY was recorded at Arsi Robe. Dashen, Mitike, Megal, ET13-A_2 and K6295-4A (all without fertilizer) had relatively higher FLY (Table 5).

The application of fertilizer did not cause significant effect on the FPC of the varieties, but at Kulumsa and Arsi Robe, the varieties showed significant difference in their FPC. Fertilizer by variety interaction was significant at Bekoji and Arsi Robe (Table 3). Highest FPC (13.2%) was recorded at Bekoji while the lowest (7.7%) was recorded at Arsi Robe. Dashen, Wabe, K6295-4A, Megal, Galama and Abola, all irrespective of fertilizer application, outsmarted in their FPC.

MDT of the varieties significantly differed at all locations and was affected by fertilizer only at Kulumsa while the interaction of the two was significant at Bekoji and Arsi Robe (Table 3). Longer MDT was recorded at Bekoji (also highest FPC) showing that the protein quality at Bekoji is better. Abola, Dashen, Galama and Megal had longer MDT at both with and without fertilizer.

The effect of fertilizer on LFV was found significant only at Arsi Robe and the varieties significantly differed in their LFV at all locations while the interaction of the two was found significant at Bekoji and Arsi Robe (same trend as in the case of FLY). Dashen, Megal, K6295-4a, Galama and Mitike had larger LFV.

Correlation coefficient (Table 7) indicated that negative correlation existed between FPC and GY. This result is in line with the fact that grain yield is inversely proportional to protein content (Nair *et al.*, 1990; Bates et al., 1980). Correlation between GY and the rest quality parameters (except LFV) was also negative. LFV also negatively correlated with FPC. The loaf volume increases with increasing protein content within a cultivar and there is linear regression between FPC and LFV above 12% FPC while it becomes curvilinear below 12% FPC (Finney *et al.*, 1987). Thus, the unusual negative correlation between FPC and LFV may be due to the very low FPC (7.7% on average) at waterlogged Vertisols of Arsi Robe location while at Bekoji high FPC (10.1-18.3%) was recorded. The correlation of FPC with HLM, TKM, and FLY was strongly positive (p 0.01). The same association existed between FLY and HLM; FLY and TKM. A high correlation existed between hectoliter weight and flour yield (Williams *et al.*, 1986).

CONCLUSIONS AND IMPLICATIONS

Test weight (HLM) of the varieties is within an acceptable range (72.8-84.0 kg/hl). According to ICARDA guidelines (Williams *et al.*, 1986), the varieties are small seeded (25-32 g/1000 kernels). Mean FPC of the varieties is in the range of 'low' to 'medium' (9.0-12.1%). Intermediate FPC (11.0-12.5%), according to ICARDA guidelines, is the most suitable for bread baking (Williams *et al.*, 1986). The low FLY recorded (68-70%) is

definitely because of the severe disease infestation (especially rust) during the growing year. It can be evidenced from the fact that FLY of the same varieties in the previous year (1997), when there was no severe disease, was above international standard [(73.0-80.5%) (Table 6)].

Four varieties: Dashen, Galama, Megal and Abola were found to possess superior quality characteristics. The FPC of Dashen (12.1%), Megal (10.8%), Galama (10.7) and Abola (10.6%) are acceptable. Abola (MDT value 3.4 min.) is categorized as 'strong' wheat while Dashen (2.9 min.), Galama (2.7 min) and Megal (2.3 min) have medium dough strength. Hence, the four varieties are the most desirable ones for good bread making because the relatively medium to long MDT value indicates their high quality gluten and hence, higher water absorption capacity (Stewart, 1984; Williams *et al.*, 1986; Finney *et al.*, 1987). The LFV of these five varieties is acceptable (827-964 ml per a loaf of 100g flour). The other varieties are categorized under 'weak' wheat and may be utilized for making biscuits.

This work is only a preliminary work on quality research of bread wheat varieties in Ethiopia. Further investigation need to be undertaken by considering additional factors such as more fertilizer levels, edaphic and meteorological data so that more detailed and reliable classification could be made on the varieties. Disease should, as much as possible, be minimized because it is obvious that disease occurrence has deleterious effect on grain quality of cereals. Economic analysis should be made on the production costs.

Furthermore, research institutes should co-work with different agro-industries and local users so that the feedback will be utilized in breeding programs to incorporate important quality controlling genes into a high yielding and disease resistant commercial varieties.

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Table 1. List of ten commercial bread wheat varieties used in quality analysis test and their description.

No.	Variety	Year released	Stature	Maturity (days)	Seed color	Altitude (m)	Yield potential (q/ha)
1	K6295-4A	1980	Tall	ML	Red	1900-2400	30-60
2	ET13-A2	1981	Tall	L	White	2200-2700	30-60
3	Pavon-76	1982	Semi-dwarf	ME	Amber	750-2200	30-60
4	Dashen	1984	Semi-dwarf	ME	Amber	2000-2600	30-60
5	Mitike	1993	Tall	ME	Amber	2000-2600	30-60
6	Kubsa	1994	Semi-dwarf	L	White	2000-2600	50-70
7	Wabe	1994	Semi-dwarf	L	Amber	< 2200	40-60
8	Galama	1995	Semi-dwarf	L	White	2200-2800	45-65
9	Abola	1997 ?	Semi-dwarf	L	White	2200-2700	40-65
10	Megal	1997 ?	Semi-dwarf	ME	Red	<2200	40-60

ML = Medium late, ME = Medium early, L = Late.

Table 2. List of parameters used in wheat quality analysis.

Parameter	Description	Measured as
FLY	Percent flour yield	Percentage of flour and bran fractions
FPC	Flour protein content	Protein of white flour (infrared reflectance spectroscopy at 12% mb)
MDT	Mixogram dough development time	Physical dough property (35 gram mixograph method)
LFV	Loaf volume	100 g long fermentation method
HLM	Test weight or hectoliter mass	Weight in kg/hectoliter
TKM	Thousand kernel weight	Weight in gram of 1000 seeds
GY	Grain yield	Weight of the grain in kilograms per hectare

Table 3. Analysis of variance for grain yield and other quality parameters of bread wheat grown at three locations in 1998.

Parameters	Source	d.f.	F-value			
			Kulumsa	Bekoji	A. Robe	Mean
GY	Location	2	--	--	--	148.77***
	F-level (F)	1	27.93***	32.53***	58.78**	31.51***
	Variety (V)	9	18.72***	66.78***	2.85*	15.90***
	F x V	9	1.52^{NS}	3.08**	0.56^{NS}	0.56^{NS}
HLM	Location	2	--	--	--	26.70***
	F-level (F)	1	1.64^{NS}	3.47^{NS}	11.84**	10.49**
	Variety (V)	9	10.71***	28.48***	3.96**	8.63****
	F x V	9	1.00^{NS}	5.83***	1.02^{NS}	1.12^{NS}
TKM	Location	2	--	--	--	11.18***
	F-level (F)	1	6.90*	1.01^{NS}	55.08***	2.32*
	Variety (V)	9	18.60***	22.60***	120.98***	4.39***
	F x V	9	0.82^{NS}	3.45**	32.69***	0.70^{NS}
FLY	Location	2	--	--	--	4.63*
	F-level (F)	1	2.60^{NS}	2.69^{NS}	70.63***	4.68*
	Variety (V)	9	14.50***	5.67***	61.43***	2.97**
	F x V	9	0.54^{NS}	3.63**	3.24**	1.59^{NS}
FPC	Location	2	--	--	--	204.19***
	F-level (F)	1	0.50^{NS}	9.80^{NS}	45.63^{NS}	10.51^{NS}
	Variety (V)	9	8.87***	1.50^{NS}	33.03***	0.92^{NS}
	F x V	9	0.89^{NS}	3.05**	14.07***	2.12*
MDT	Location	2	--	--	--	6.47**
	F-level (F)	1	5.00*	1.02^{NS}	1.37^{NS}	1.54^{NS}
	Variety (V)	9	166.05***	14.24***	34.36***	27.86***
	F x V	9	1.16^{NS}	1.71^{NS}	11.80***	0.47^{NS}
LFV	Location	2	--	--	--	64.90***
	F-level (F)	1	1.00^{NS}	4.02^{NS}	86996.78***	3.75^{NS}
	Variety (V)	9	7.57***	2.60*	209890.42***	0.38^{NS}
	F x V	9	0.64^{NS}	3.44**	66503.75***	1.66^{NS}

*, **, *** indicate significance at the 5, 1 and 0.1% levels of probability, respectively.
NS indicates non-significance.

Table 4. Mean grain yield and physical quality parameters of ten commercial bread wheat varieties grown at three locations in 1998.

Variety	F-level	GY (kg/ha)				HLM (kg/hl)				TKM (g)			
		KU	BK	AR	Mean	KU	BK	AR	Mean	KU	BK	AR	Mean
Abola	F_0	4680	262	1216	2840	82.3	71.5	80.0	77.9	25.2	18.4	35.5	26.4
	F_1	6160	263	2178	3658	83.9	76.5	85.7	82.1	27.7	22.1	29.6	26.5
Dashen	F_0	3725	770	677	1724	78.9	74.6	75.0	76.1	27.5	34.2	27.0	29.6
	F_1	3910	168	1249	1776	77.2	71.7	73.1	74.0	27.3	30.4	29.0	28.9
ET13-A2	F_0	4787	5899	562	3749	80.1	80.3	80.5	80.3	29.3	35.6	25.0	30.0
	F_1	4820	6077	1792	4230	81.8	81.5	80.3	81.2	29.0	33.6	27.1	29.9
Galama	F_0	6219	3678	1278	3725	79.5	68.8	75.9	74.8	26.4	19.3	32.7	26.1
	F_1	6549	5641	2359	4850	82.4	73.9	83.4	79.9	28.9	23.5	34.6	29.0
K6295-4A	F_0	5879	3812	1762	3818	83.7	75.8	85.1	81.5	32.3	30.7	29.2	30.7
	F_1	6522	4931	2768	4740	83.7	77.3	85.7	82.3	32.4	30.2	33.2	31.9
Kubsa	F_0	5103	3115	1185	3134	75.6	68.4	74.4	72.8	27.0	19.8	31.3	26.0
	F_1	5508	5662	2570	4580	76.5	74.0	83.1	77.9	26.9	27.5	33.7	29.4
Megal	F_0	3579	2985	1392	2652	82.3	80.1	83.2	81.9	28.6	24.0	32.9	28.5
	F_1	4429	4033	1923	3462	85.2	80.9	86.0	84.0	30.5	25.9	31.9	29.4
Mitike	F_0	5593	6213	1188	4331	83.9	81.6	73.5	79.7	33.2	31.1	26.4	30.2
	F_1	7839	8170	2075	6028	80.0	83.0	80.9	81.3	34.2	32.9	26.5	31.2
Pavon-76	F_0	5173	1970	1012	2718	80.5	68.4	80.1	76.3	27.3	20.2	26.3	24.6
	F_1	6307	2803	2479	3863	81.6	69.5	81.2	77.4	29.2	23.1	30.2	27.5
Wabe	F_0	3670	703	1104	1826	77.7	77.3	70.2	75.1	26.9	21.1	27.2	25.1
	F_1	4408	859	2264	2510	77.4	70.5	81.2	76.4	27.2	18.1	29.8	25.0
Mean	F_0	4840.8	2940.7	1137.6	3051.7	80.5	74.7	77.8	77.6	28.4	25.4	29.4	27.7
	F_1	5645.2	3860.7	2165.7	3969.7	81.0	75.9	82.1	79.7	29.3	26.7	30.6	28.9
G. Mean		5243.0	3400.7	1651.7	3510.7	80.7	75.3	79.9	78.6	28.9	26.1	30.0	28.3
CV		14.0	20.2	32.1	22.4	2.8	3.3	6.7	4.3	4.9	16.9	2.1	7.9
LSD		1185.0	1177.3	866.4	1086	3.2	3.4	7.3	4.6	2.338	4.116	1.045	4.496

F_0 = 0 fertilizer; F_1 = 60-60 N-P_2O_5.
KU = Kulumsa; BK = Bekoji; AR = Arsi Robe.

Table 5. Mean chemical quality parameters of ten commercial bread wheat varieties grown at three locations 1998.

Variety	F-level	FLY (%)				FPC (12% m.b.)				MDT (min)				LFV (ml)			
		KU	BK	AR	Mean	KU	BK	AR	Mean	KU	BK	AR	Mean	KU	BK	AR	Mean
Abola	F_0	52.3	49.7	54.4	52.1	10.2	13.7	7.8	10.6	4.4	2.7	3.1	3.4	798.0	1019	692.0	836.0
	F_1	52.9	51.0	52.1	52.0	9.8	12.8	6.7	9.8	4.3	3.4	2.2	3.3	800.0	989	748.0	846.0
Dashen	F_0	53.5	75.5	46.2	58.4	10.0	18.3	7.9	12.1	2.5	3.5	2.5	2.9	801.0	1330	759.0	964.0
	F_1	50.8	52.7	45.1	49.5	9.8	10.1	7.3	9.0	2.5	2.8	2.5	2.6	787.0	826	680.0	764.0
ET13-A2	F_0	54.5	54.3	55.9	54.9	10.8	12.2	8.2	10.4	1.5	1.2	1.5	1.4	880.0	825	716.0	807.0
	F_1	54.4	53.7	52.4	53.5	11.0	12.1	8.5	10.5	1.4	1.5	1.5	1.5	883.0	841	744.0	823.0
Galama	F_0	52.8	47.4	53.1	51.1	10.9	14.4	7.0	10.7	3.1	2.7	2.5	2.7	875.0	983	700.0	853.0
	F_1	53.0	50.6	51.7	51.8	10.3	13.0	6.9	10.1	3.1	2.5	2.2	2.6	837.0	993	688.0	839.0
K6295-4A	F_0	56.0	50.2	56.3	54.1	11.1	12.2	9.5	10.9	1.8	1.5	1.8	1.7	862.0	879	836.0	859.0
	F_1	54.0	51.0	51.8	52.3	11.2	12.4	7.8	10.4	1.6	1.?	2.1	1.6	848.0	867	680.0	798.0
Kubsa	F_0	56.0	48.6	55.0	53.2	10.1	13.2	7.0	10.1	2.1	2.1	2.4	2.2	867.0	947	736.0	850.0
	F_1	54.6	53.0	51.2	53.0	10.0	12.0	6.6	9.5	2.2	2.0	2.2	2.1	878.0	932	692.0	834.0
Megal	F_0	57.8	55.1	54.6	55.8	10.5	12.9	8.9	10.8	2.9	2.0	2.0	2.3	818.0	957	728.0	835.0
	F_1	58.3	55.1	53.0	55.5	10.8	12.6	7.4	10.3	2.5	2.0	2.5	2.3	830.0	971	784.0	862.0
Mitike	F_0	59.5	59.7	53.1	57.4	10.3	12.2	7.4	10.0	2.1	1.8	2.5	2.1	818.0	937	796.0	851.0
	F_1	58.6	57.2	51.0	55.6	10.4	11.7	8.0	10.0	2.1	1.9	2.8	2.3	790.0	936	748.0	825.0
Pavon-76	F_0	56.7	47.9	53.0	52.5	9.90	14.1	7.6	10.5	2.6	2.1	2.5	2.4	878.0	912	525.0	772.0
	F_1	56.6	46.3	50.3	51.1	10.2	13.5	8.0	10.6	2.5	2.0	2.2	2.2	857.0	927	684.0	822.0
Wabe	F_0	53.3	48.0	46.7	49.3	10.1	15.3	8.2	11.2	2.0	1.9	2.1	2.0	832.0	893	756.0	827.0
	F_1	51.3	46.4	46.2	48.0	9.7	13.6	7.9	10.4	1.9	1.8	2.2	2.0	810.0	860	732.0	801.0
Mean	F_0	55.2	53.6	52.8	53.9	10.4	13.9	8.0	10.7	2.5	2.2	2.3	2.3	842.9	968.2	724.4	845.4
	F_1	54.5	51.7	50.5	52.2	10.3	12.4	7.5	10.1	2.4	2.1	2.2	2.3	832.0	914.2	718.0	821.4
G. Mean		54.8	53.1	51.5	53.2	10.3	13.2	7.7	10.4	2.5	2.2	2.3	2.3	836.2	948.0	948.2	833.4
CV		3.3	16.0	0.7	6.7	3.6	16.3	3.3	7.7	6.4	23.4	6.3	12.0	4.5	16.0	15.8	12.0
LSD		3.1	14.1	0.5	8.3	0.5	3.5	0.3	2.1	0.3	0.9	0.2	0.5	252.4	252.4	252.4	177.2

F_0 = 0 fertilizer; F_1 = 60-69 N-P_2O_5.
KU = Kulumsa; BK = Bekoji; AR Arsi Robe.

Table 6. Mean physical and chemical quality parameters of ten commercial bread wheat varieties grown at Kulumsa in 1997.

Variety	HLM (kg/hl.)	TKM (g)	FLY (%)	FPC (12% m.b.)	MDT (min)	LFV (ml)
Abola	82.3	33.3	77.3	10.8	3.4	885
Dashen	77.7	37.8	74.9	10.6	2.5	940
ET13-A2	81.3	36.0	73.0	9.5	1.5	885
Galama	83.8	45.9	76.1	8.7	3.0	830
K6295-4A	77.1	32.3	75.7	10.8	2.6	1100
Kubsa	81.2	37.6	80.5	10.7	1.6	90.5
Megal	83.3	37.1	78.7	10.6	2.5	950
Mitike	79.2	32.0	76.6	10.5	3.0	945
Pavon-76	78.6	32.1	76.4	9.9	2.5	965
Wabe	81.1	39.7	78.4	10.3	2.2	920
Mean	80.6	36.4	76.8	10.2	2.5	851.1

Table 7. Correlation coefficients of grain yield and other quality parameters of bread wheat grown at three locations in 1998.

Parameters	GY	HLM	TKM	FLY	FPC	MDT
HLM	-0.2279					
TKM	-0.0101	0.9107**				
FLY	-0.1395	0.9815**	0.9488**			
FPC	-0.1699	0.6205**	0.8104**	0.6821**		
MDT	-0.0926	0.0739	0.3617	0.1527	0.8168**	
LFV	0.9904**	-0.1646	0.0560	-0.0852	-0.1324	-0.0925

** denotes significant r-value at 0.01 probability level.

RESPONSE OF BREAD WHEAT GENOTYPES TO DROUGHT SIMULATION UNDER A MOBILE RAIN SHELTER IN KENYA

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ABSTRACT

Development of drought tolerant wheat genotypes for marginal areas of Kenya would enhance utilization of the marginal areas of the country, which comprise 83% of the total national land area. Simulated drought under a rain shelter provides a good alternative to screening in the semi-arid areas which are vast and widespread. This method excludes rainfall and allows other variables to fluctuate naturally. Moisture regimes simulated included terminal, early, mid and late droughts, and were created under a mobile rain shelter at Njoro, Kenya in 1998 and 1999. The drought responses of five wheat varieties, Duma, R748, R830, R831 and R833 were determined. Five differing moisture regimes were created under the mobile rain shelter by applying drip water (i) up to seedling stage (70 mm), (ii) through tillering (82 mm), (iii) up to anthesis (94 mm), (iv) up to grain filling (106 mm), and (v) at all stages (118 mm). Data was collected on yield and yield components during the growing season from seedling to maturity. Analysis of variance was carried out in each season and data from the two seasons were combined. Terminal and early drought caused significant reduction in tiller number and number of reproductive tillers while mid to late droughts caused significant reduction in ear length (16.9%), spikelets/head (14.3%), and 1000-kernel weights (22.4%), and an increase in the number of sterile florets/head (28.3%) as compared to the control. Seedling and reproductive stages were the most critical stages for moisture requirement. Genotype R748 performed well in all moisture regimes, and it should be recommended for commercial production in the dryland areas. It is possible to select drought tolerant cultivars using mobile rain shelters for drought simulation in Kenya.

INTRODUCTION

Wheat is an important cereal crop in Kenya and contributes significantly to food security in the country. Worldwide wheat is among the nine crops of major importance propagated by seed (Neergard, 1979). It can effectively be grown in drought prone areas if suitable varieties are developed. In Kenya, wheat is currently grown by both large-scale and small-scale farmers. Kenyans have continued to develop feeding habits which include wheat products in their diet. The National wheat requirement has not been met by domestic production although wheat production has continued in the high potential areas. This is partly due to diminishing arable land as a result of increasing population. The marginal rainfall areas (lower elevations), which consist of 83% of total land area, has economically under-utilized arable potential of about 200,000 hectares which can be put under production with appropriate technology (World Bank, 1989). Low (200-400 mm), erratic, unreliable (45% C.V.) and short

rainfall in these areas normally cause frequent crop failures. Irrigation and development of drought resistant varieties would be the most appropriate technologies for utilizing these areas for crop production.

Carrying out dryland research is usually expensive and time consuming due to the travel required to reach these vast areas. Research results are dependent on annual weather changes which are often unreliable. The experiments are usually exposed to unreliable rainfall amounts and timing. Other research methodologies such as glasshouse potted plants have been developed to induce stress under controlled environments (Pennypacker *et al.*, 1990; Rossouw and Wagmhmarae, 1995) and incorporation of osmoticum like ethylene gylcol into the growth medium (Schapendok *et al.*, 1989). However, use of glasshouse has problems of creating an artificial environment for crop growth and it's also limited by initial cost while in potted plants stress develops more rapidly due to limited container size. Use of osmoticum interferes with phosphate uptake resulting in additional nutrient stress. A rain shelter offers a good alternative for drought simulations because it excludes rainfall while allowing environmental variables to fluctuate naturally (Coles *et al.*, 1997). This allows the crop to acclimatize to the stress which develops gradually as it usually occurs in the field. It also allows the experimenter to have control over the amount and time of moisture application. It then becomes possible to study different stages of wheat development and their response to drought. Irrigation is costly, slow to take root and can only benefit few farming communities apart from high initial capital outlay. Development of drought tolerant wheat cultivars may be the most effective long-term solution to this problem. It could make a large impact in wheat production thus providing food security and income to the farming communities in these areas.

Previous investigations of wheat yield response to water supply during various stages of development indicated that reproductive development is more sensitive to water deficits than vegetative growth stage (Entz and Fowler, 1988; Simane *et al.*, 1993; Ravichandran and Mungse, 1995). Drought stress from heading to maturity gave greater reduction in grain yield than from emergence to tillering (Imityaz *et al.*, 1990). Post-anthesis grain yield loss was reported to be associated with kernel abortion or reduction in kernel growth leading to low grains per head and low kernel weights (Hossain *et al.*, 1990). Severe water stress from seedling stage to maturity reduced all grain yield components, particularly the number of fertile ears per unit area, grain number per head, dry matter and harvest index (Giunta *et al.*, 1993). Higher number of tillers per plant may not result in higher yields because some tillers may not significantly contribute to yield because of tiller abortion (Dewey and Albrechtsen, 1985).

In an attempt to reduce the costs involved and time taken in identifying suitable wheat genotypes for marginal areas, this study was undertaken to determine drought responses of five wheat genotypes under simulated drought conditions and the most critical stage(s) that require moisture in wheat under tropical dry conditions in Kenya.

MATERIALS AND METHOD

The experiment was conducted under a mobile rain shelter for two seasons, 1998 and 1999, at the National Plant Breeding Research Centre, Njoro (0^0 20^0S, 35^0 56'E; 2160 m a.s.l.). During the period of the experiment, maximum temperature recorded was 27.9°C. A mobile rain shelter was used to exclude rain and induce drought stress (Legg *et al.*, 1978; Upchurch *et al.*, 1983; Jefferies, 1993). It consisted of an open-ended 15m long by 7m wide (105 m^2)

shelter roof mounted on wheels, which roll on two parallel, elevated concrete barriers and is covered by translucent sheets which allowed up to 90% photosynthetic photon flux density to pass through. The length of the rail is 30 meters, hence the shelter rests on half the runway. The barrier also helps to prevent rainwater from flooding the shade. The wheels that rest on the rails make it possible to move the shelter either away from the plots to expose the crop during non-rainy times or over the plots when it rains. In this experiment, the crop was covered only when raining. Drip irrigation (Chapin Watermatics, 1999) was used and each plot was irrigated separately by controlling gates and nozzles of the irrigation system. The main pipe was laid along 15 m length and spaced at 40 cm, while the laterals (delivery pipes) were laid between the rows and spaced 30 cm apart (40 x 30 cm). One delivery pipe was shared by two rows, hence each main plot had two delivery pipes. The pressure of the water into the irrigation set was set automatically by use of pressure regulators which ensured that the total amount of water which was supplied by each nozzle remained constant in the whole experimental plot.

The experimental design was a split-plot where each experimental unit had 4 rows, 1 m long and 20 cm between the rows, with 3 replicates. Main plots included five moisture regimes where four stress environments and one non-stress environment were created by having different dates of irrigation termination (from seedling establishment to grain filling) to simulate different types of drought stress that commonly occur in marginal areas of Kenya during the cropping season. Drought was created by terminating irrigation at different growth stages, which included: 1) Terminal drought (at seedling establishment): 46 mm of water was applied during the first week and additional 12 mm each was applied at 2nd and 4th week after planting and irrigation terminated until maturity (70 mm). 2) Early drought (at tillering): Irrigation was applied as 1 above and 12 mm applied at 6th week after which irrigation was terminated until maturity (82 mm). 3) Mid drought (at anthesis): Irrigation was applied as 2 above and 12 mm was applied at the 8th week then irrigation was terminated until maturity (94 mm). 4) Late drought (at grain filling): Irrigation was applied as 3 above and additional 12mm were applied at 10th week then irrigation was terminated until maturity (106 mm). 5) Control (up to maturity): Water was applied as 4 above and additional 12 mm was applied at 12th week (118 mm). All treatments had equal amount of water applied to field capacity at planting by irrigation which enabled the seeds to germinate uniformly. Water treatments were not randomized in order to keep the incremental change in water application between adjacent treatments as small as possible, as suggested by Fernandez (1991) and Steyn *et al.* (1995). This reduced the chances of water movement, especially if very wet (control) and dry (terminal drought) regimes were bordering each other, when the greater gradient in soil water content would promote water movement between plots. Sub-plot had four wheat genotypes, R748, R830, R831, R833 and the variety Duma as a check.

Data were taken on the following parameters from the inner two rows: plant height at maturity, number of tillers per plant on ten randomly selected plants before booting, percent reproductive tillers at maturity, ear length on primary tillers, days to 50% heading and maturity, number of spikelets per head, number of seeds per head and sterile florets per head, 1000-kernel weight and grain yield per hectare.

Data was analyzed using SAS (SAS, 1996) and means separated using LSD, where ANOVA showed significant differences.

RESULTS

The mean ANOVA (Table 1) showed that there was significant difference (p=0.01) between watering regimes and among genotypes tested for grain yield. The control treatment had the highest yield for all genotypes in both seasons while the terminally stressed treatment (70 mm) had the lowest yield (Table 2). In both seasons, the treatments where the lowest quantity of water were applied had the lowest number of seeds per head, number of tillers per plant, percent reproductive tillers, spikelets per head and kernel weight, while treatments where more moisture was applied recorded higher values (Table 2). The most stressed conditions also recorded the highest number of sterile florets per head and the plants with shortest ears. Generally, yield and yield components decreased with increasing moisture stress. Genotype R748 had the highest mean grain yield followed by Duma, while R830 and R831 were the lowest yielders (Table 3). Genotype R833 had the highest number of seeds per head in both seasons followed by R748 and Duma while R830 attained the lowest overall number of seeds per head (Table 3). Genotype R831 had the longest ears and second highest number of spikelets per head after R833 and highest number of sterile florets per head. R748 had the lowest number of sterile florets per head and highest seed weight followed by Duma. R833 had the lowest seed weight and shortest ears followed by R830 in both seasons (Table 3). R830 and R748 headed and matured last while Duma and R833 were the earliest maturing genotypes. R748 were the longest plants while R833 and Duma were the shortest (Table 3). Genotype R831 and R830 produced the highest number of tillers per plant but recorded the lowest number of reproductive tillers while R833 and R748 produced the lowest tiller number but number of highest reproductive tillers.

DISCUSSION

Severe water stress from seedling stage to maturity reduced expression of all yield components. Terminal and early drought reduced grain yield by 62.2% and 52.7% as compared to 44.3% and 21.4% loss by mid and late drought when compared to control. These show that reproductive stage was the most critical stage that required moisture followed by seedling stage. Duma and R748 suffered highest yield loss under mid to late season drought while R830, R833 and R831 were affected more by early drought, showing that there was genotypic differences in response to drought stress.

Highest yield loss during reproductive stages was associated with reduced number of seeds per head (20.3%), increased number of sterile florets per head (28.3%), reduced number of reproductive tillers (13%), reduced length of ears and number of spikelets per head (16.9% and 14.3%, respectively) and reduced kernel weights (22.4%) for all genotypes (derived from Table 2). Kernel weight was affected more by moisture stress from grain filling to maturity. Soil moisture deficits could have hastened the ear emergence period, flowering and pollination which consequently resulted in poor or incomplete pollination and poor seed set. Moisture stress from grain filling to maturity was strongly associated with reduced number of seeds per head (11.8%) and kernel weights (14.7%) which could have been caused by shortened grain filling periods and reduced carbohydrate supply. There was increased kernel abortions under these conditions. Highest reduction in ear length and spikelets per head occurred under mid-late season drought because soil moisture deficits could have affected spike vegetative development. Genotype R831 and R830 had the highest number of tillers per plant but lowest number of reproductive tillers because of tiller abortions. Abortive tillers contributed to low yield in these genotypes because they compete with main culm for

resources without significantly contributing to yield. Hence selection for few tillers/plant is ideal for improving drought stress in wheat.

Drought stress hastened all phenological stages and the normal period of growth and development was affected resulting in reduced dry matter production and final yield. Duma and R833 were early maturing cultivars and therefore, they exhibited drought escape as drought tolerance mechanism. R748 maintained superior performance under all moisture conditions irrespective of being late maturing. Hence late maturing cultivars can be grown in marginal areas although they may suffer yield reduction during grain filling, but not all-late maturing wheat cultivars will succumb to drought stress.

CONCLUSION

Early and terminal drought are critical in bread wheat, causing the high yield reduction while affecting all yield components. Mid and late drought causes more effect on reproductive stages. Seedling and reproductive stages are more sensitive to moisture requirement in wheat, hence there is need to develop varieties that are tolerant to drought at these stages. Late maturing genotypes (e.g., R830 and R831) were sensitive to early drought as compared to early maturing cultivars such as Duma. However, R748 was the best cultivar across all watering regimes, although it is a late maturing genotype and hence it could be recommended to be grown in marginal rainfall areas. Duma remains a good variety for marginal areas. Use of mobile rain shelter for drought simulations enabled selection of apparently drought tolerant cultivars. Morphological, physiological and biochemical studies need to be undertaken to assess how these tolerant varieties were able to grow, adapt and produce yield in drought environment.

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Table 1. Combined mean squares for analysis of variance (ANOVA) for yield and yield components measured during two seasons (1998/99) under rain shelter at Njoro, Kenya.

Source	df	Grain yield
Rep	2	1628.84
Water	4	3414.31**
Season	1	70.836 ns
Rep*water	8	820.23
Water*season	4	405.70*
Main plot error	10	854.52
Genotype	4	696.47**
Genotype*season	4	49.02*
Genotype*water	16	44.12*
Genotype*water*season	16	31.94*
Subplot error	80	34.14
Total	149	
Mean		843.2
MSE		5.84
C.V.(%)		21.64

*, ** Significant at p = 0.05 and 0.01, respectively; ns = not significant; df = degrees of freedom; C.V. = coefficient of variation; MSE = mean sums of squares for error.

Table 2. Mean separation for yield and yield components measured at different watering levels during each of the two seasons (1998 and 1999) and combined over the two seasons under rain shelter at Njoro, Kenya.

Wat. (mm)	PHT (cm)	DH	DPM	TLR	RTR	EA	SPK	Seeds/ head	SF	1000-KWT	Grain yield (kg/ha)
1998											
118	49.8a	60.9a	100.5a	2.5a	96.3a	7.5a	11.3a	30.1a	4.3c	38.9a	1525.9a
106	42.0a	58.2b	96.5b	2.4a	92.9b	6.7b	10.5b	25.0b	5.7b	32.4b	1029.7ab
94	31.2a	56.9c	94.3c	2.1b	81.6c	6.2c	9.3c	22.8c	6.1b	30.2b	694.7b
82	27.9bc	54.4d	92.1d	6c	69.1d	15.6c	9cd	20.2d	86.7a	27.5bc	587.2b
70	21.0c	52.8e	91.1d	1.2d	63.1e	4.8d	8.3d	18.7d	7.9a	27.3c	431.9b
Mean	34.4	56.7	91.1	1.9	80.2	6.2	9.7	23.4	6.2	31.3	850.9
1999											
118	45.1a	61.7a	94.9a	2.7a	96.3a	6.8a	11.1a	25.8a	6.1d	31.8a	1117.9a
106	42.8b	60.1b	92.5b	2.5ab	92.4a	6.3b	10.6b	24.6b	6.7c	27.8b	970.5b
94	41.3c	57.7c	90.9c	2.3b	85.1b	5.9c	9.9c	21.8c	7.4c	24.7c	784.2c
82	38.3d	55.9d	89.5d	1.5c	73.7c	5.1d	9.4d	20.8d	8.6b	23.4d	676.3d
70	36.6e	54.5e	87.3e	0.8d	67.2d	5.0e	8.6e	19.4e	9.1a	21.4d	561.3e
Mean	40.8	58.0	91.0	1.9	82.9	5.8	9.9	22.5	7.6	25.8	822.2
Both seasons combined											
118	47.3a	61.3a	97.7a	2.6a	96.3a	7.1a	11.2a	28.0a	5.3d	35.3a	1321.9a
106	42.4a	59.2b	94.5b	2.4a	91.7a	6.7b	10.6b	24.7b	6.2d	30.1b	1037.5b
94	36.3b	57.3c	92.6c	1.8b	83.3b	5.9c	9.6c	22.3c	6.8c	27.4b	733.1c
82	33.1bc	55.2d	90.8d	1.5c	71.4c	5.3d	9.2d	20.5d	7.8b	25.4c	625.0c
70	28.8c	53.7e	89.2e	1.0d	65.2d	4.9e	8.5e	18.9d	8.4a	24.5c	500.0d
Grand mean	37.6	57.3	93.0	1.9	81.6	6.0	9.8	22.9	7.0	28.6	834.4

Values followed by the same letter are not significantly different at 5% level of lsd.
Wat = watering regimes; PHT = plant height; RTR = percent reproductive tillers; DH = days to 50% heading; DPM = days to 50% maturity; KWT = kernel weight; EA = ear length; SPK = spikelets per head; SF = sterile florets per head; TLR = tillers per plant.

Table 3. Mean separation table for yield and yield components of five wheat genotypes tested during each of the two seasons (1998 and 1999) and combined over the two seasons under rain shelter at Njoro, Kenya.

Geno-type	PHT (cm)	DH	DPM	TLR	RTR	EA	SPK	Seeds/ head	SF	1000-KWT	Grain yield (kg/ha)
1998											
R748	45.0a	58.6b	100.3a	1.9c	87.9a	6.7b	9.5d	24.5b	4.8d	35.6a	1134.4a
Duma	30.5c	52.9e	89.0d	2.0c	86.6a	6.4c	9.6c	23.5b	5.4c	32.5b	913.3b
R833	26.5c	55.0d	90.5d	1.6d	89.5a	5.1e	11.0a	27.5a	5.5c	28.5c	832.5b
R831	36.0b	56.9c	95.1c	2.2a	64.6c	7.1a	10.2b	22.1c	8.4a	32.8b	723.0cd
R830	33.9b	60.0a	98.2b	2.1b	72.1d	5.4d	8.3e	19.3d	6.7b	23.6c	674.7d
1999											
R748	43.6a	61.1b	95.8a	1.7c	88.3a	6.1b	9.4c	22.9b	6.0d	30.6a	990.0a
Duma	39.8c	51.6d	86.3d	1.9d	86.9a	6.0b	10.0b	22.6b	6.9c	28.4a	883.8b
R833	37.5d	54.2c	86.9d	1.5e	90.3a	4.9d	10.9a	25.9a	6.1d	22.9c	814.4c
R831	41.2b	60.7b	91.7c	2.5a	72.7b	6.5a	10.5a	20.8c	10.1a	23.7b	691.6d
R830	42.0b	62.4a	94.3b	2.2b	75.8b	5.4c	9.0c	19.9d	8.9b	23.6c	729.7d
Both seasons combined											
R748	44.3a	59.9b	98.0a	1.8d	88.5ab	6.5b	9.2d	23.7b	5.4e	33.3a	1072.2a
Duma	35.1c	52.2e	88.4d	1.9c	86.8b	6.2c	9.8c	23.2b	6.2c	30.3b	868.4b
R833	32.0d	54.6d	88.7d	1.6e	89.9a	5.1e	10.9a	26.5a	5.8d	25.7d	821.7b
R831	38.6b	58.8c	93.4c	2.3a	68.7d	6.9a	10.4b	21.4c	9.2a	28.3c	721.9c
R830	38.0b	61.2a	96.0b	2.1b	74.0c	5.3d	8.7e	19.6d	7.8b	25.4d	702.2c
Grand mean	37.6	57.3	93.0	1.9	81.6	6.0	9.8	22.9	6.9	28.6	843.8

Values followed by the same letter are not significantly different at 5% level of LSD test.
PHT = plant height; RTR = percent reproductive tillers; DH = days to 50% heading;
DPM = days to 50% physiological maturity; KWT = kernel weight; EAR = ear length;
SPK = spikelets per head; SF = sterile florets per head; TL= tillers per plant.

DEVELOPING WHEAT VARIETIES FOR THE DROUGHT-PRONE AREAS OF KENYA: 1996-1999

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ABSTRACT

Drought prone areas in Kenya have recently attracted more attention from both researchers and policy makers. In order to enhance the economic potential of these areas, the development of bread wheat varieties that tolerate drought is being emphasized. Yield trials were carried out from 1996 to 1999 to identify bread wheat genotypes which would perform well in Katumani, Elmentaita, Mogotio and Lañet — representative dry sites in Kenya. In each year, there were about 14 lines tested in comparison with check varieties Duma and Ngamia. Genotype, genotype x environment and environmental differences were observed. At the end of the trials, a new wheat variety, "Chozi", was released for commercial production. Its yield ranged from 0.5 to 2.5 t/ha over years and locations.

INTRODUCTION

Shortage of water is a chief cause of variation in wheat yields (Jamieson *et al.*, 1995). A global effort has ensued to explain how water stress causes yield to vary, and to develop wheat varieties which can withstand this stress. Development of drought tolerant wheat varieties involves the selection of genotypes with inherent characters that lead to efficient use of scarce moisture. Varieties respond differently to varying water stress conditions, with soil water being more important than total rainfall *per se*. Relatively small rain events, however numerous, may have little impact on soil water due to evapotranspiration and may not lead to sustained growth. Biomass production in water stress conditions has been related to evapotranspiration (Jamieson *et al.*, 1995). Evapotranspiration itself has been associated with the drying soil conditions while plant growth has also been shown to be strongly associated with transpiration. Delayed sowing decreases yield potential, but early sowing may lead to total crop loss due to reduced soil water. All these complex crop-water relationships confound selection of germplasm for the dry areas.

It is necessary that crops are identified which are drought tolerant, to make use of the large land area that experiences drought conditions, and on which the inhabitants do not carry out any economically successful crop production. This may be due to the unsuitability of the crops that they grow. Wheat is expected to be one of the suitable crops that are both a food, as well as, a cash crop.

Wheat has globally been recognized as one of the most widely adapted crops (Smale, 1996), and therefore it is possible to identify varieties of this cereal that will tolerate drought. Adaptability of the varieties will be the factor, otherwise it has been demonstrated that wheat can be grown in very dry conditions (CIMMYT, 1992).

Wheat imports into Kenya have been ranging at about 60% of demand for the last few years. This is quite costly both to government foreign exchange, and to the country as a whole due to discouragement of Kenyan farmers, and misuse of liberation process and the problems which come with grain imports. Development of wheat varieties for the marginal, drought prone areas in Kenya is therefore of great importance (Kinyua, 1994). A possible total of 300,000 ha is targeted, once the right variety is identified and is adopted by the farmers.

The following study was carried out to identify wheat germplasm that is suited to the dry areas of Kenya. The specific objectives of the study were to screen introduced wheat germplasm at 4 locations in dry areas of Kenya; to test the yield potential of elite wheat germplasm in these areas; and, the adaptability of these lines in diverse environments in Kenya.

MATERIALS AND METHOD

Yield trials were conducted from 1996 to 1998 in four dryland sites in Kenya. Planting was done during the rainy season at each site. Recommended agronomic practices were applied. Marginal Areas Wheat Performance Trial (MAWPT-96), with 16 entries was planted at four sites in 1996. The trial was planted in a randomized complete block design with plot size of 8 rows of six meters each in 3 replicates. The check varieties included were Duma, currently the highest yielding variety in dry, and K. Chiriku, a high yielding wheat variety in the traditional higher rainfall wheat growing areas.

Six selected accessions and 4 check varieties were evaluated at Katumani. and 4 other sites in 1997. These entries were planted in randomized complete block design with three replicates. The plot size was 8 rows of 6 meters. An estimated 100 kilograms of DAP per hectare was applied to each plot. The 6 selected accessions were R744, R745, R748, R751, R754 and WL170/84. The check varieties were Duma, Pasa, K. Chiriku and K. Mbweha.

The 1998 National Dry Land Wheat Performance Trial (NDLWPT-98) was planted at Mogotio, Elmentaita, Lanet and Katumani. There were 9 entries and Duma as the check variety. The design was RCBD with 3 replicates. The plot sizes were 8 rows of 6 meters while the spacing between the rows was 20 cm and there was a 0.5 m path between blocks. The data collected on this trial was drought tolerance on 1 to 5 scale, grain yield and test weight.

RESULTS AND DISCUSSION

The effective rainfall was very low in 1996, considering high evapotranspiration in the dry areas due to high temperatures and high wind velocity, and few wind breaks. This could be expected to affect plant growth, and therefore yield. The recovering of the crops, however, was fair although the end result (yields) were not statistically analyzable. However, it gives an indication of what the farmer expects in such difficult conditions. In all the cases, the rains ceased after the trials had germinated and began again too late for benefit.

Table 1 shows the average yields for the MAWPT-96 from Katumani against the overall average for the four test sites. R744, R751, R754, Duma and WL170/84 ranked high in Katumani. R751 ranked high in the three sites. The variability in these marginal areas and the unreliability of the rainfall complicated the performance of the tested lines. On visual

selection R748, R751, R754, R744, Duma and WL170/84 were selected in Katumani in 1996. There were significant site (F=1107.23**) and variety (F=2.28**) differences (Table 2). The site by variety interaction was also significant (F=1.74*). This indicates that the changing environments interact differently with individual genotypes leading to change in relative ranking for the test genotypes over locations.

Table 1 also shows the average 1000-kernel weight. The lowest seed weights were recorded in Katumani (data for other sites not shown). This implies that grain filling was influenced positively by availability of moisture. R748 recorded the highest seed weight at Katumani. Other lines with high seed weight at this site were R742, R744 and Duma (Table 1).

Table 3 shows the analysis of variance for 1000 kernel weight at three sites. The varieties as well as the sites differ significantly (F=38.07** and 95.86**, respectively). The variety by site interaction was also significant (F=4.78**). The varieties reacted differently to these conditions, thus showing significant varietal as well as variety by environment interaction differences (Table 3). These reactions can be exploited during selection. A variety that is responsive to environmental change and would positively utilize the conditions of a better environment is more desirable. Such would be capable of tolerating drought stress in bad weather conditions.

Table 4 shows the ANOVA for yields and test weight, at Katumani, and 3 other sites in Kenya in 1997. The entries differed significantly on yield in Katumani. Indeed these entries showed differences at p=0.01 at Katumani. The CV for Katumani was high. The ANOVA (Table 4) shows that there were site differences. The entries as well as the interaction effects were also significant, apart from the interaction effect of test weight. This indicates that the entries showed different response over the environments and that there was genotype by environment interaction. This was similar to what was observed in the previous year.

Table 5 shows the means for yield and test weight in Katumani and overall mean for 4 environments. In Katumani R744 performed best while R748 was also relatively well ranked and slightly differing with R744 only. It was just as good as the 2nd in ranking. Entry R748 yielded above average in Katumani as well as over all environments. These same lines performed well in 1996. Since the environmental conditions differed in the two years (weather data not shown), these lines show stability characters and also positive response to good environments, thus maintaining relatively high ranking in both adverse and good environments. These are desirable characteristics for wheat varieties for dry areas. They will be able to respond to the good years in these environments, as well as tolerate adverse years.

The yields differed significantly in Katumani this year, while there were no significant differences in kernel weight (Table 5). Since there were line differences when the sites were combined in the analysis (Table 4), it might be that the conditions in Katumani during grain filling were so adverse that the different lines were not able to express their inherent potential in grain weight. Moisture conditions at grain filling period is very critical in determining the seed quality characteristics of wheat (Kimurto, 2000). There were site differences in influencing both yields and kernel weight (Table 4). Due to this, the lines that would perform relatively well in all environments would possess desirable characteristics of a suitable variety for the dry areas in Kenya. These areas will once in a while receive rainfall that is high enough to be comparable to good environments (Jaetzold and Schimdt, 1983). The rainfall in these areas is however, very erratic both in amount and reliability. It is important,

then, for a variety meant for these areas to be able to cushion the weather changes that are most certain to occur over time. Genotype R748 is one such.

Table 6 shows the ANOVA for grain yield and test weight for the NDLWPT-98. The yields did not vary significantly at Narok or Lanet. There was significant difference between the yield of the entries in Elmentaita (Gmss=0.28*) and Mogotio (Gmss=0.27*). The mean yields were low in Narok and Elmentaita, ranging between 0.5 t/ha to 1.02 t/ha and 0.4 to 1.2 t/ha respectively (Table 7). The yields were higher in Mogotio (range 1.7-2.8 t/ha) and Lanet (ranging 1.5-2.3 t/ha). Only R748 yielded less than Duma in Elmentaita, while in Mogotio all the entries yielded higher than Duma. Mogotio was relatively the best site on yields while Narok was the worst. Test weight was highly variable over all the sites (Table 6), with a range between 64 and 78 kg/hl (Table 7). R831 had the highest test weight in Lanet and Narok. The lowest test weights were observed in Mogotio (ranging 65-70 kg/hl). This site had relatively the highest yields, which gives the indication that yields are negatively correlated to test weight. From the data it was evident that Duma is still performing relatively very well in the dry areas of Kenya.

R748, which was released in December, was also performing very well both in yield and test weight. R748 was released under the variety name "Chozi", in December 1998. About 1.5 tons of Breeder's Seed of the variety was harvested in Timau in late February, 1999 for distribution to seed merchants.

CONCLUSION

Development of wheat varieties for the drylands in Kenya for the period 1996 -1999 culminated in the release of variety "Chozi" which will contribute greatly in wheat production in the country.

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Questions and Answers:

J.A. Adjetey: (a) There is a need for quantitative measure of plant water status; (b) there is a need to postulate a physiological/morphological basis for drought tolerance.

Answer: Some quantitative measures have been undertaken, e.g., morphology of roots for drought tolerance. Other studies are planned.

Table 1. Mean yields (t/ha) and 1000 kernel weight (KWT) in grams, for MAWPT-96 for Katumani and overall means for 4 sites in 1996.

	KWT (grams)		Yield (t/ha)	
Entry	**Katumani**	**Grand mean**	**Katumani**	**Grand mean**
R659	29.27	36.49	0.233	1.422
R742	40.20	40.58	0.167	1.422
R744	38.37	39.50	0.267	1.311
R745	35.40	38.19	0.167	1.688
R748	46.63	46.92	0.167	1.533
R751	35.77	38.83	0.267	1.767
R754	34.83	36.96	0.233	1.656
DUMA	44.13	41.40	0.233	1.367
R641	32.10	35.94	0.133	1.322
WL170/84	32.00	34.29	0.200	1.433
GAMTOOS	37.80	38.82	0.133	1.467
PALMIET	29.30	32.20	0.167	1.200
NGAMIA	33.43	36.86	0.133	1.156
K.NYANGUMI	29.00	31.80	0.133	1.167
PASA	32.50	37.02	0.200	1.378
KWALE	34.33	37.46	0.166	1.163
Mean	35.32	37.70	0.187	1.403

Table 2. Analysis of variance for yields in MAWPT-96 at 3 locations in Kenya.

Source	**DF**	**SS**	**F**
Site	2	344.835	1107.23**
Rep	6	0.496	0.53
Variety	15	5.319	2.28**
Var x Site	30	8.136	1.74*
Error	90	4.676	

C.V = 28.09 R^2 = 0.962 Mean = 1.405

Table 3. Analysis of variance for Kernel weight in MAWPT–96 for 3 sites in Kenya in 1996.

Source	DF	SS	MSS	F
Replicate	2	10.702	5.351	1.73
Site	2	593.015	296.507	95.86**
Variety	15	1766.337	117.756	38.07**
Site/variety	30	443.092	14.770	4.78**
Error	94	290.750	3.093	
Total	143	31903.895		

Table 4. Combined analysis of variance for yield, test weight and plant height for NDWPT-97 from 4 sites in Kenya in 1997.

	Mean sums of squares			
	DF	Yield	Test weight	Plant height
Location	3	138.00**	130.98**	15345.72
Error	8	0.549	2.011	60.34
Lines	9	0.753**	12.96**	16.88**
Loc x Line	27	0.360**	1.71ns	68.28**
Error	72	0.126	1.39	26.40
CV		14.40	1.50	6.47

Table 5. Means for Yield and 1000 Kernel Weight for Katumani for NDWPT-97 grown in 4 sites in Kenya in 1997.

Entry	Yield	1000 KWT
R744	0.54A	25.47A
R745	0.32B	25.00A
R748	0.29BC	26.44A
R751	0.27BC	22.79A
R754	0.11CD	25.73A
WL170/84	0.04D	27.82A
Duma	0.53A	26.15A
Pasa	0.17BCD	25.62A
K. Chiriku	0.27BC	24.55A
K. Mbweha	0.03D	26.42A

Table 6. ANOVA for yield and test weight (TWT) for NDLWPT-98 grown in Narok, Lanet, Elmentaita and Mogotio in 1998.

Source	df	Mean Sum of Square							
		Narok		Lanet		Mogotio		Elmentaita	
		Yield	TWT	Yield	TWT	Yield	TWT	Yield	TWT
Genotype	9	0.16	5.91**	0.24	20.16*	0.27*	19.04	0.28*	21.34**
Replicate	2	0.10	0.23	0.63	6.70	0.20	0.63	0.01	0.10
Error	18	0.10	0.68	0.27	8.77	0.12	4.34	0.10	0.47

Table 7. Mean yield (t/ha) and TWT (kg/hl) for NDLWPT-98 grown in Narok, Lanet, Elmentaita and Mogotio in 1998.

Genotype	Narok		Lanet		Mogotio		Elmentaita	
	Yield	TWT	Yield	TWT	Yield	TWT	Yield	TWT
R830	0.69	74.33	1.84	70.33	2.32	68.33	1.21	72.00
R831	0.71	77.00	1.76	78.00	1.91	70.33	0.49	74.67
R833	0.90	75.00	2.19	69.67	2.08	66.00	0.73	70.00
R836	0.47	74.67	2.25	74.67	2.34	68.33	0.76	76.00
R837	0.94	74.67	1.53	76.67	2.12	68.67	0.74	72.67
R839	0.56	74.00	2.17	73.33	2.09	64.67	1.02	72.00
R840	0.49	75.67	1.88	72.33	1.79	65.33	0.81	71.33
R841	0.77	76.33	1.47	75.00	2.19	69.67	1.17	74.00
R748	1.02	76.67	1.69	74.67	2.71	71.33	0.30	66.33
Duma	0.53	72.33	2.13	73.33	1.67	64.00	0.42	72.00
Mean	0.69	75.07	1.89	73.80	2.12	67.67	0.76	72.10

MILLING AND BAKING QUALITY OF SOUTH AFRICAN IRRIGATED WHEAT CULTIVARS

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ABSTRACT

The objective of this study was to examine the effect of environment, genotype and their interaction on bread-making quality characteristics of spring wheat cultivars grown under irrigated conditions. Wheat grain samples were obtained from experimental trials conducted by the Small Grain Institute, at six locations in 1997 and at seven locations in 1998. Nine cultivars were common in both years, with two unique in 1997. Statistical analyses showed that genotype, environment and their interaction had significant influence on quality characteristics. Canonical variate analysis (CVA) allowed grouping of characteristics to discriminate among genotypes, locations and interaction effects. The results show that cultivars T4, SST876 and Palmiet were poorer in bread-making quality than Kariega, SST57, SST822, SST825, and Inia which showed good potential as quality bread wheat cultivars.

INTRODUCTION

The recent deregulation of the single-channel wheat marketing system and the introduction of a more liberal grain marketing environment in South Africa has had a drastic effect on the purchasing practices of food processors. In the single-channel marketing system, wheat cultivars were released for commercial production after meeting minimum quality requirements (11 primary and 11 secondary parameters) set by the Wheat Technical Committee, functioning under the auspices of the former Wheat Board, and comprising of representatives from a broad spectrum of the industry. These cultivars were released for production purposes only and hence, were deemed to be of equal quality worth and the grain was mixed at the point of receipt (e.g., Wheat Board collection silos). Grain buyers were obliged to receive and accept grain of these mixtures of cultivars for milling and baking purposes, irrespective of the absolute quality (minimum BL2 grade) of the grain. As a consequence, cultivars with inherently superior quality characteristics were never objectively identified nor could demand for high quality grain by the processing industry be catered for.

The newly liberalized wheat-marketing environment in South Africa allows purchase on an individual cultivar basis, a common practice in many countries, that have deregulated wheat-marketing systems. However, limited or unscientific information regarding relative milling and baking quality of South African wheat cultivars is available to breeders, producers, buyers and processors of grain. Howard and Wessels (1997) have put forward an exemplary selection-index to quantify the relative milling and baking value of South African wheat

cultivars. While a significant contribution to the industry, there are deficiencies in this scheme which are rightly acknowledged.

Thus, the environment was suitable for a scientific study be undertaken to determine the relative milling and baking value of South African bread wheat cultivars. Outside South Africa similar investigations of the mechanism and magnitude of genotypic and environmentally related influences on wheat quality (Lukow and McVetty, 1991; Peterson *et al.*, 1992; Graybosch *et al.*, 1995) have been performed. In addition, complications in the interpretation of the interrelated nature of quality characteristics have been well documented (Preston *et al.*, 1992; Rasper, 1993), and a better understanding of the factors associated with quality variation is required.

A study was undertaken to determine the relative milling and baking quality of South African bread wheat cultivars for three major production regions: summer-rainfall dryland winter wheat, winter-rainfall dryland spring wheat and irrigated spring wheat. In this paper, the results of the latter are reported for the 1997 and 1998 crop seasons.

MATERIALS AND METHODS

Field Trials

Eleven spring wheat cultivars were grown under irrigation in the summer rainfall region. Cultivar identity and location details are presented in Table 1. All trials were executed according to standardized field procedures. Quality analyses (Table 2) were performed on grain obtained from each replication.

Statistical Analyses

The additive main multiplicative interaction (AMMI) method (Gauch, 1988) and the canonical variate analysis (CVA) (Digby *et al.*, 1989) were used to statistically analyze the data. The results from the AMMI are provided in the form of simple ANOVA, means for environments and genotypes, and biplots showing the extent of genotype and environment interaction. This method integrates analysis of variance (ANOVA) for the genotype and environment main effects with principal components analysis of the genotype by environment interaction, and is especially useful in analyzing multilocation trials (Gauch and Zobel, 1988). According to Purchase (1997), the AMMI model can summarize patterns and relationships of genotypes and environments, as well as provide valuable prediction assessment. While other multivariate analysis procedures (e.g., cluster analysis) may be difficult to interpret in relation to genotype by environment interaction, the AMMI model offers relevant biological information whereby principal component factors can be described according to environmental and/or biological factors, and is statistically fairly simple.

Canonical variate analysis is used to show differences between groups than between individuals. Differences between a large number of variables are firstly reduced to a smaller set of variables that account for most of the range. This new set, called the canonical variates, is linear combinations of the original measurements, and is thus given as vectors of loading for the original measurements. With this approach, a set of directions is obtained in such a way that the ratio of between-group variability to within-group variability in each direction is maximized (Digby *et al.*, 1989; Van Lill and Purchase, 1995). This test was therefore used to see which parameter had more influence on quality for both main (genotype and

environment) and interaction effects. Taking into account that phenotypic variation is an indication of genetic potential, quality analysis of the cultivars will be used to reveal their quality status and to predict blending complementarity to improve quality potential.

Separate analyses were performed for 1997 and 1998 to determine phenotypic correlations, canonical variate to find groupings between genotypes, environments as well as a canonical variate analyses to find groupings between environment and genotype. A combined analysis for 1997 and 1998, where only the nine cultivars (entries) included in both years, was also performed and for the purpose of this discussion we will concentrate only on the combined analysis.

RESULTS AND DISCUSSION

Discriminate scores (Table 3) indicated that only 7 quality parameters were responsible for observed genotype variations, including vitreous kernels (VK), mixograph development time (MDT), alveograph configuration ratio (P/L), alveograph strength (Str), SDS-sedimentation (SDSS), loaf volume at 12% protein (LFV 12%) and SKCS hardness index (HI). These variations were likely associated with endosperm starch and protein content, and the rate of starch to protein caused differences between the two years.

The combined CVA performed to find groupings between genotypes for both crop cycles explained 72.8% and 18.7% for axis 1 and axis 2 respectively, the total being 91.5% (Table 4).

It is evident from Table 4 that there was a big contrast between the two seasons (1997 and 1998) but the pattern of genotypes within seasons was similar. This is due to intermediate negative CV1 scores versus intermediate to low positive scores. The horizontal separation (CV1) accounted for 72.8% of the total variation and thus made a large contribution. Also the interaction effects shown by T4, Palmiet and to a lesser extent SST 57 and SST 876 deviated more from the others.

The correlations between variates (Table 5) show vitreous kernels had a positive correlation ($r = 0.63$) with SKCS-hardness index. The correlations with alveograph P/L ratio ($r = 0.40$) and alveograph strength were also positive ($r = 0.38$) but slightly lower. Optimum endosperm starch and protein contents are very important for alveograph P/L ratio and in particular vitreous kernels and SKCS-hardness index. Increase or decrease in either starch or protein may cause dilution (lack of sufficient bonds for interaction) in the other and these results in lower values for these parameters. This was the case for 1998 where grain filling was higher at all sites. Mixograph development time showed high positive correlation with alveograph strength ($r = 0.71$) and lower positive correlation with SDS-sedimentation ($r = 0.38$) and loaf volume at 12% protein ($r = 0.45$). All of these four parameters show a positive relationship with each other and are indicative of better protein quality.

The alveograph P/L ratio showed a fairly high positive correlation with SKCS hardness index ($r = 0.65$) and a negative correlation with SDSS (-0.548). The positive relationship between the two former parameters could relate to harder wheats having slightly more starch damage with subsequent distortion of extensibility versus stability of the alveograph. This is also reflected in the negative correlation of $r = 0.67$ between SDSS and SKCS hardness index values. Sodium dodecylsulfate sedimentation volume (SDSS) measures the flour protein aggregate ability, which was probably damaged.

The main variates which discriminated between interaction effects CV1 (x-axis) (Figure 1) were SDS-sedimentation (r = 0.958), SKCS-HI (r = 0.781), alveograph P/L ratio (r = -0.571) and vitreous kernels (-0.563), which had the most significant correlation with CV1 scores (Table 5).

The main variates which discriminated between interaction effects for CV2 (y=axis) (Figure 1 and Table 5) were mixograph development time (r = -0.91), alveograph strength (r = -0.85) and loaf volume (12% protein) (r = -0.57). The CV2 accounted for 18.7% of the total variation.

Therefore in conclusion, Figure 1 shows that the pattern for most genotypes within seasons was very similar. This is shown by codes 2 and 12 (T4), 8 and 16 (SST876), 9 and 17 (SST57), 4 and 11 (Kariega), 6 and 14 (SST825), 5 and 15 (SST822), 7 and 18 (Inia), 3 and 10 (Marico). Palmiet (codes 1 and 13) showed unstable quality characteristics. This shows that despite the environmental conditions having influence on quality parameters, genotype potential should be the prime objective together with positive environmental interactions. In ascending order, genotypes like T4; Palmiet and SST876 had less potential for most of the parameters, particularly T4 and Palmiet. Nevertheless, Palmiet showed positive environmental interactions in some locations and it may perform well, also the performance was intermediate at most of the sites when the environments were not as ideal as it was during 1997. SST57 showed intermediate potential, whereas Marico, Kariega, SST822, SST825 and Inia showed intermediate to higher potential. Therefore these genotypes may give desirable results at most of the sites for various parameters despite seasonal environmental variations.

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Table 1. Cultivars and locations, 1997 and 1998.

Cultivar	Origin	Year	Locations	Year
Marico	Small Grain Institute	1997/98	Bull Hill	1997, 1998
Kariega	Small Grain Institute	1997/98	Barkley-West	1997, 1998
T4	Small Grain Institute	1997/98	Prieska	1997, 1998
Palmiet	Small Grain Institute	1997/98	Hopetown	1997, 1998
SST 825	Sensako	1997/98	Douglas	1997, 1998
SST 822	Sensako	1997/98	Loskop	1997, 1998
SST 876	Sensako	1997/98	Koedoeskop	1998
SST 57	Sensako	1997/98		
SST 55	Sensako	1997		
SST 65	Sensako	1997		
Inia	Small Grain Institute	1997/98		

Table 2. Milling and baking quality tests conducted on grain obtained from 11 spring wheat cultivars grown under irrigated conditions.

Milling quality tests	Dough quality tests	Baking quality tests	Gluten quality tests
• Grain protein content (Leco and NIR) – AACC 39-11	Flour protein content – AACC 39-11	Baking test – AACC 10-09	Wet Gluten test
• Break flour yield	Mixograph (MDT) – AACC 54-40A		SDS-sedimentation (SDSS) – AACC 56-57
• Bühler mill flour extraction – AACC 26 – 21A	Farinograph – AACC 54-21A		
• Vitreous kernels (VK)	Alveograph (P/L) – AACC 54-30A		
• Thousand kernel mass			
• Falling number – AACC 56-81B			
• Flour color			
• Hectoliter mass			
• Single Kernel Characterization System, diameter, hardness and moisture content			

Table 3. Discriminate scores of latent vectors for genotypes, 1997 and 1998 seasons combined.

PCAN	Axis 1	Axis 2
VK	-0.0075	-0.0416
MDT	-0.1138	-1.8264
P/L	0.9121	1.0203
Str	-0.0685	-0.0440
SDSS	0.2216	0.0008
LFV12%	-0.0002	-0.0046
Hl	-0.0624	0.0049

Table 4. Discriminant scores for group means for genotypes, 1997 and 1998 combined.

Seas x Gen		CV1 72.8%	CV2 18.7%	Seas x Gen		CV1	CV2
1	97 Pa	-3.535	-0.539	10	98 Ma	3.914	-1.237
2	97 T4	-4.408	3.265	11	98 Ka	4.871	-0.297
3	97 Ma	-3.315	-2.506	12	98 T4	0.477	3.614
4	97 Ka	-0.986	-0.641	13	98 Pa	1.233	2.471
5	87 82	-2.506	-1.135	14	98 85	2.294	-0.738
6	97 85	-3.908	-1.054	15	98 82	3.415	-0.149
7	97 In	-2.447	-1.726	16	98 86	2.655	1.465
8	97 86	-4.468	0.547	17	98 57	1.704	-0.949
9	97 57	-3.992	-0.190	18	98 In	4.073	-0.865

Pa - Palmiet T4 - T4 Ma - Marico
Ka - Kariega 82 - SST 82 85 - SST 857
In - Inia 86 - SST 876 57 - SST 57

Table 5. Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

VK	1.000						
MDT	0.158	1.000					
P/L	0.395	-0.195	1.000				
Str	0.377	0.712	0.035	1.000			
LFV12%	0.051	0.449	-0.120	0.471	1.000		
SDSS	-0.400	0.383	-0.548	0.229	0.386	1.000	
HI	0.627	-0.011	0.650	0.604	-0.010	-0.667	1.000
CVA1	-0.563	0.172	-0.571	-0.027	0.240	0.958	-0.781
CVA2	-0.478	-0.909	0.104	-0.848	-0.565	-0.261	-0.157
	VK	MDT	P/L	Str	LFV12%	SDSS	HI

Table 6. Mean values of the 18 G x E interactions (two years) for all variates considered in the canonical variate analysis

Seas x Gen		VK	MDT	P/L	SDSS	Str	HI	LFV12%
1	PA 97	82.51	2.35	0.70	54.27	32.19	74.99	939.6
2	T4 97	72.80	1.18	0.85	43.67	16.45	74.37	846.0
3	Ma 97	84.93	3.15	0.62	57.47	39.03	72.30	944.7
4	Ka 97	80.13	2.28	0.53	64.87	34.13	67.42	962.7
5	82 97	89.47	2.45	0.58	60.60	32.47	77.82	934.1
6	85 97	85.87	2.42	0.81	55.33	38.51	78.80	951.8
7	In 97	85.05	2.62	0.66	60.87	41.24	69.58	978.9
8	86 97	80.27	1.89	0.72	49.27	30.01	76.00	927.3
9	57 97	72.27	2.40	0.53	51.40	30.51	72.63	914.7
10	Ma 98	68.78	2.91	0.40	85.22	32.93	60.86	937.1
11	Ka 98	65.89	2.40	0.36	87.83	31.05	57.53	976.6
12	T4 98	57.33	1.30	0.57	62.00	13.56	61.83	843.4
13	Pa 98	55.00	1.71	0.51	66.61	17.86	59.89	898.8
14	85 98	67.11	2.64	0.67	78.72	37.71	63.09	962.9
15	82 98	59.00	2.49	0.37	81.61	29.91	60.82	979.8
16	86 98	60.72	1.77	0.40	75.72	26.42	57.57	942.3
17	57 98	65.78	2.81	0.31	74.44	28.95	61.59	959.8
18	In 98	62.22	2.69	0.45	84.72	37.12	53.76	982.9
	Mean	71.09	2.30	0.55	67.37	30.36	66.07	938.4

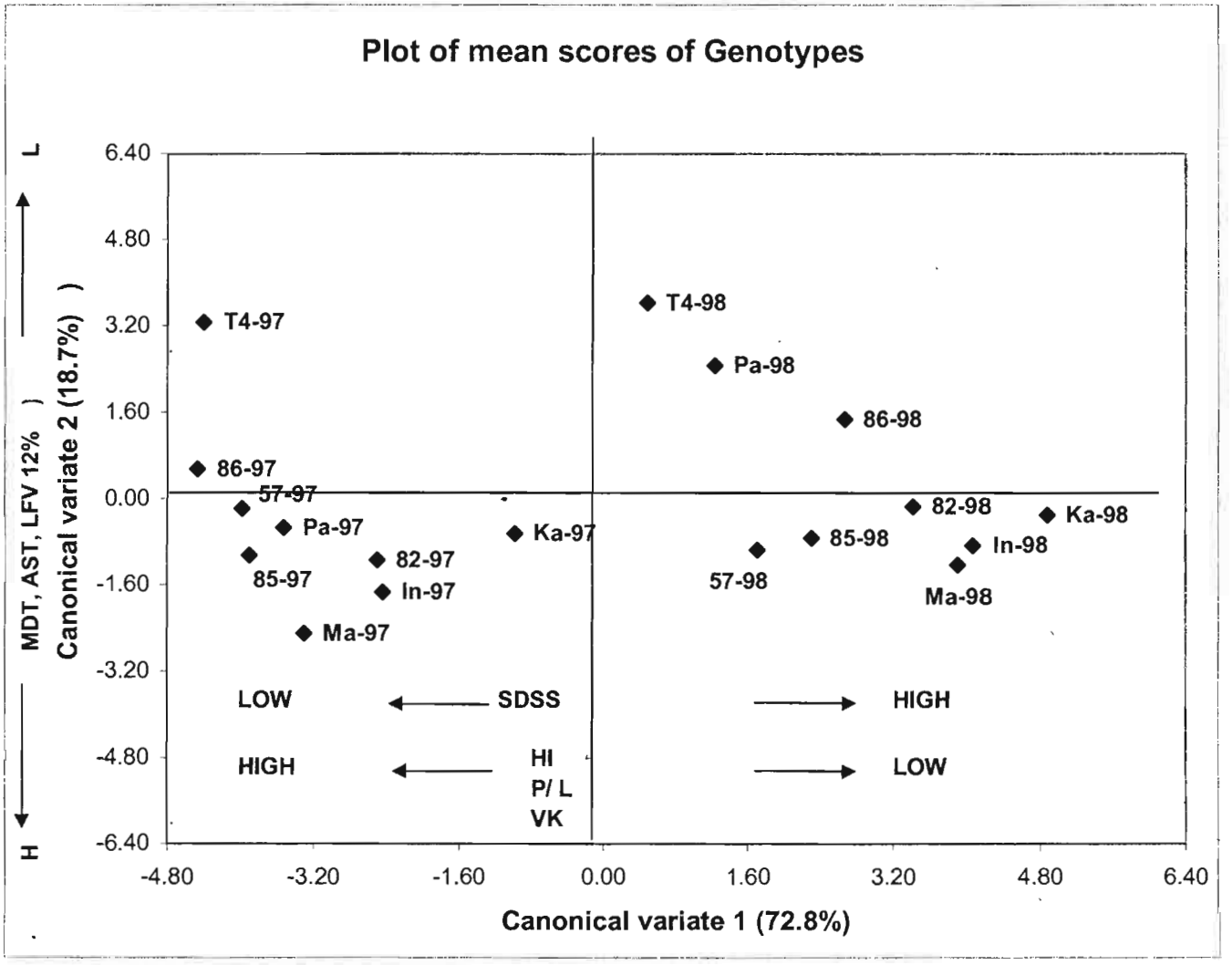

Figure 1. **Canonical biplot of mean scores for genotypes for the 1997 (97) and 1998 (98) seasons for nine cultivars**

T4	**-**	**T4**	**Ma**	**-**	**Marico**	**Ka**	**-**	**Kariega**
57	**-**	**SST 57**	**Pa**	**-**	**Palmiet**	**82**	**-**	**SST 822**
86	**-**	**SST 876**	**In**	**-**	**Inia**	**85**	**-**	**SST 825**

RESPONSE OF ELITE WHEAT GENOTYPES TO SOWING DATE IN THE NORTHERN REGION OF THE SUDAN

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ABSTRACT

High temperature is a major environmental constraint that limits wheat cultivation in tropical and subtropical environments. Nonetheless, considerable variability in bread wheat performance under heat stress conditions has been reported. In Sudan, the wheat growing season is short (i.e., 90-100 days). Farmers, particularly in the northern region, often delay wheat planting until December to January, exposing the crop to heat stress. Delayed plantings are often associated with substantial grain yield losses, estimated at up to 86% at farm level. A field study was carried out at Hudeiba for three years, 1995/96-1997/98, with the objective of advising farmers on the selection of cultivars that suit best to their intended planting time. Fifteen elite bread wheat genotypes were planted at optimum (mid-November) and late (mid-December) sowing dates. Delaying sowing date by one month reduced grain yield by 27%, and genotypes exhibited significant differential response to sowing date. Genotype HD2380 was superior under both early and late plantings. However, medium maturity cultivars, such as "Seri 82", "Debeira" and "Wadi el Neil", should be planted at the optimum date, while the early maturity cultivars such as "Condor", "Nacozari" and "Fang 60", perform best when late sowing is unavoidable.

INTRODUCTION

High temperature is the major environmental constraint that limits wheat production in the tropical and subtropical hot environments. The prevalence of hot spells at the beginning or at the end of the wheat crop growth cycle can be detrimental to economic (grain) productivity. High temperatures usually hasten the crop developmental rates (Fischer, 1985), reduce duration of developmental phases and eventually decrease wheat productivity per unit area. Nonetheless, considerable variability in bread wheat performance under heat stress conditions has been reported (Morgunov, 1994), and some morpho-physiological traits were reported to be associated with heat tolerance in wheat (Reynolds *et al.*, 1994).

In Sudan, wheat is produced as an irrigated, winter season crop. The duration of the winter season fluctuates and is generally short, 90 to 100 days (Ageeb, 1994). Farmers, particularly in the northern region, often delay planting their wheat crop to December or January, and priority for early planting is usually given to grain legumes (Ibrahim, 1993) which are more highly rewarded cash crops. Delays beyond the optimum planting date of wheat are often associated with substantial grain yield losses, estimated at up to 86% at farm level (Ibrahim, 1996). However, Ibrahim (1996) reviewed sowing date studies in the Sudan and reported

differential response of wheat cultivars to sowing date.

The current study attempts to evaluate the yield performance of elite wheat genotypes under optimum and late sowing dates, with the ultimate goal of providing recommendations to farmers on cultivar selection suitable to date of sowing. It is hoped that such recommendations would maximize farmers' yields from optimum sowing dates and minimize yield losses when late planting is unavoidable.

MATERIALS AND METHODS

Fifteen bread wheat genotypes, including the commercial cultivars (Condor, Debeira, Wadi el Neil and El Neilain), were selected from the collaborative research activities with national, regional and international (CIMMYT and CIMMYT/ICARDA) wheat improvement programs. Genotypes inclusion was based on performance over the preceding 3-4 seasons. The selected genotypes were planted within a range of optimum sowing dates (mid-November) and after the optimum range of sowing dates (mid December) for 3 consecutive seasons (1995/96-1997/98) at Hudeiba Research Farm (17° 34'N, 33° 56'E; 350 m a.s.l.) in the northern region of Sudan.

The experimental design used was a split-plot (main plots were assigned to planting dates and subplots were assigned to genotypes) with 3 replications. A net area of 11 m^2 (1995/96) and 4.8 m^2 (1996/97 and 1997/98) was used for the final grain yield harvest. Nitrogen fertilizer, in form of urea, was applied uniformly to all experimental plots at the rates of 86 kg ha^{-1} N (1995/96 and 1996/97) and 107.5 kg ha^{-1} N (1997/98). The crop was kept weed-free and irrigated at 8-12 day intervals.

The data collected included: meteorological data (daily ambient air temperature) crop phenology, biomass yield, grain yield and yield components. Statistical analyses were carried out using MSTATC statistical program. (1984). Analysis of variance for all characters studied was made separately for each season as well as combined analysis over seasons.

RESULTS AND DISCUSSION

Thermal Environments

The prevailing thermal regimes during the three growing seasons are described as follows:

- The 1995/96 season exhibited late season (late-January to late-March) heat stress of about 1-4°C above the long-term (1986/87-1998/99) average (LTA).
- In contrast, the 1996/97 season experienced early season (December to mid-January) heat stress of about 1-5°C above the LTA.
- The 1997/98 season was an "average" season with a very short mid-season (late-January to early-February) heat stress.

Grain Yield

The analysis of the grain yield data (Tables 1-3) revealed that grain productivity was significantly influenced by the season, planting date, genotype and the interactions of planting date x season, genotype x planting date and genotype x planting date x season.

Season Effect

The highest seasonal average grain yield (4714 kg ha^{-1}) was obtained in the third growing season (Table 1a). The lower grain yields in the other two seasons could be attributed to late and early heat stresses, respectively. In contrast, less heat stress was experienced in 1997/98 cropping season.

The late heat stress of 1995/96 resulted in a low partitioning efficiency of assimilates (reduced harvest index) and reduced grain-filling (small kernel size) in comparison to the 1997/98 season (Table 1a). On the other hand, early heat stress (1996/97) caused reductions in total assimilate (biomass) production and the number of spikes m^{-2}.

Sowing Date Effect

Delaying planting date by one month (from 15 November to 15 December) reduced grain productivity by 27% (Table 1b) because the crop was exposed to heat stress during the grain filling period. The reductions in grain yield of late planted crops were reflected by low biomass productivity, low fertility (fertile spikes m^{-2}), poor grain-fill (small kernel size), weak partitioning efficiency of assimilates (reduced harvest index), shorter crop growth cycle, and shorter plant stature (Table 1b).

Genotype Effect

Averaged over seasons and planting dates, the productivity of genotypes ranged from 3930 (12300) to 4464 kg ha^{-1} (HD2380) with a grand average productivity of 4100 kg ha^{-1} (Table 1c). The productivity of the commercial cultivars ranged from 4055 (Wadi el Neil) to 4263 kg ha^{-1} (Condor). Only one entry (HD2380) was superior to the best check (Condor). However, four genotypes (HD2380, Seri82, Nacozari and Fang60) exhibited yields higher than mean yield performance of the commercial cultivars (4092 kg ha^{-1}).

Planting Date x Season Effect

Reduction in grain yield due to late planting varied significantly between seasons (Table 2a). Delayed planting in 1995/96 resulted in the most severe reduction (37%) in grain yield in comparison to 1996/97 (25%) and 1997/98 season (21%). The observed severe reductions in grain yield of late planted crop in 1995/96 season could be attributed to the hot period (1-4°C) that prevailed during spike formation and grain-fill phases.

Genotype x Planting Date Effect

In the ranged optimum planting dates, grain yield of the wheat genotypes ranged from 4583 to 4984 kg ha^{-1} (Table 2b). The highest yielding genotypes were Seri82 (4984 kg ha^{-1}), HD2380 (4927 kg ha^{-1}), Debeira (4871 kg ha^{-1}), F6bulk (4816 kg ha^{-1}), Wadi el Neil (4802 kg ha^{-1}) and El Neilain (4800 kg ha^{-1}). With the exception of HD2380, all genotypes are of the medium maturity types (Table 2b).

On the other hand, in the range of late planting dates, grain yield of the evaluated wheat genotypes ranged from 3068 to 4000 kg ha^{-1} (Table 2b). The highest grain yield in this environment was displayed by the genotypes HD2380 (4000 kg ha^{-1}), Condor (3793 kg ha^{-1}),

Fang60 (3744 kg ha^{-1}) and Nacozari (3743 kg ha^{-1}), and all of these genotypes are early maturing types (Table 2b). It should be noted that the Indian genotype HD2380 was superior under both early and late planting situations. In addition, this genotype was characterized by a stable short crop growth cycle (Table 2b).

The above results are in agreement with those reported by Ibrahim (1996) and confirm the differential response of wheat genotypes to planting date. For farmers to obtain maximum yield, the best option is to cultivate high yielding, medium maturing genotypes within the range of optimum sowing dates. When late planting is unavoidable, the best option to minimize yield losses associated with late planting is to cultivate high yielding, early maturing genotypes such as HD2380, Condor, Fang60 or Nacozari.

Genotype x Planting Date x Season Effect

In late plantings, in each of the three growing seasons, the genotypes HD2380, Condor, Fang60 and Nacozari were consistently ranked among the highest yielding genotypes (Table 3). With optimum planting and, in seasons characterized by mid to late season heat stress (1995/96 and 1997/98), the genotypes HD2380 and Seri82 ranked among the highest yielding genotypes. Unfortunately, when exposed to early heat stress (during optimum planting, 1996/97 season) these two genotypes ranked among the lowest yielding genotypes (Table 3).

CONCLUSIONS

1. Delaying the planting date of the wheat crops by one month (mid-November to mid-December) in Northern Sudan resulted in substantial grain yield losses (27%).

2. Among commercial bread wheat cultivars, the medium maturing varieties Debeira, Wadi el Neil and El Neilain should be planted early.

3. Seri82 proved superior at optimum planting dates and is recommended as a strong candidate for release as a commercial variety for the northern region.

4. The genotype HD2380 is superior under both optimum and late planting. In addition, the genotype HD2380 has shown a number of acceptable traits e.g., early maturity (96 days) and high single kernel weight. This genotype is recommended for both early and late plantings.

5. When late planting is unavoidable cultivation of early maturing cultivars such as HD2380, Condor, Fang60 and Nacozari can help in minimizing the grain yield losses associated with late planting.

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Questions and Answers:

Amanuel Gorfu: In selecting the sowing dates, what is the basis for taking Nov. 15 as the first sowing date? If you had considered another sowing date before Nov. 15, do you think Nov. 15 would still remain an optimum sowing date?

Answer: The optimum range of sowing dates at Hudeiba extends from 1st November to 1st December, that is why we selected the mid point of the range, i.e., 15 November.

Table 1. Effect of season, planting date and genotype on mean grain yield and other crop characters at Hudeiba Research Farm, 1995/96- 97/98.

Treatment	Grain yield (kg/ha)	Biomass yield (kg/ha)	Harvest Index (%)	Days to maturity	Spikes per m^2	Grains per spike	Kernel weight (mg)	Plant height (cm)
(a) Season effect:								
1995/96	3744	11912	31.1	102	428	44.7	37.2	90
1996/97	3843	10703	35.8	101	295	38.9	38.0	81
1997/98	4714	12862	36.7	101	450	37.4	39.8	90
Effect	***	**	***	NS	***	***	*	***
SE±	75	232	0.25	0.3	5	0.27	0.42	0.3
(b) Planting date effect:								
15 November (OPT)	4750	13260	36.1	104	414	40.8	41.8	90
15 December (LPT)	3451	10391	33.0	99	367	39.9	34.9	83
Effect	***	***	***	***	***	**	***	***
SE±	61	189	0.20	0.2	4	0.22	0.35	0.3
(c) Genotype effect:								
Seri 82	4247	11442	36.8	102	365	47.9	36.7	83
HD2380	4464	11800	37.5	96	433	31.2	46.5	84
Nacozari	4212	11395	36.9	95	405	39.7	36.5	81
Glennson	3998	11943	33.4	101	376	44.2	35.3	88
Giza 165	3987	11875	33.4	104	305	47.4	39.7	92
Debeira	4184	12368	33.7	104	392	39.4	38.8	88
Genaro 81	4053	11727	34.5	101	347	46.9	34.8	80
Gemmeiza 1	3960	11575	34.0	104	302	47.5	39.6	93
Wadi el Neil	4055	11815	34.1	104	399	39.1	39.7	90
Fang 60	4187	11198	37.4	93	406	36.4	38.9	88
Condor	4263	11944	35.8	100	478	34.6	37.2	76
F6bulk [a]	3942	12020	32.5	104	414	40.9	35.1	87
12300 [b]	3930	12287	31.6	104	432	35.7	37.1	88
145F6 [c]	3959	12059	32.7	104	419	35.3	36.5	87
El Neilain	4068	11936	33.9	104	388	39.1	42.6	95
Effect	***	***	***	***	***	***	***	***
SE±	82	142	0.60	0.3	11	0.61	0.35	0.7
C.V.(%)	8.5%	5.1%	7.4%	1.4%	11.7%	6.4%	3.8%	3.4%

a = F6bulk L.2606-90/91; b = 12300X14PYTV(NH243); and c = 145F6-79/80X14PYTV(NH248).
*, **, *** = Significant at 5, 1 and 0.1% probability levels, respectively.
NS = Not significant.
OPT = Optimum planting time and LPT = Late planting time.

Table 2. Effect of planting date within season and genotype within planting date on mean grain yield and other crop characters at Hudeiba, 1995/96-97/98.

Treatment	Grain yield (kg/ha)	Biomass (kg/ha)	Harvest Index (%)	Days to maturity	Spikes per m^2	Grains per spike	Kernel weight (mg)	Plant height (cm)
(a) Planting date x season effect:								
OPT x 1995/96	4607	14008	32.9	106	444	46.9	40.7	94
LPT x 1995/96	2882	9817	29.3	98	412	42.6	33.7	86
OPT x 1996/97	4389	11495	38.3	103	332	38.1	42.0	81
LPT x 1996/97	3297	9911	33.3	99	258	39.7	34.1	80
OPT x 1997/98	5256	14278	36.9	103	468	37.4	42.6	96
LPT x 1997/98	4173	11446	36.4	98	431	37.5	37.0	85
Effect	*	*	**	**	**	***	NS	***
SE±	106	328	0.35	0.4	7	0.39	0.60	0.4
(b) Genotype x planting date effect:								
Optimum planting date (15 November)								
Seri 82	4984	12872	38.8	105	378	48.3	40.4	86
HD2380	4927	12731	38.6	97	465	30.2	48.5	84
Nacozari	4680	12395	38.1	96	455	37.5	38.5	83
Glennson	4669	13325	35.4	104	378	46.3	39.1	91
Giza 165	4655	13633	34.3	107	311	49.4	43.6	97
Debeira	4871	14146	34.5	107	421	40.2	42.3	92
Genaro 81	4713	13143	36.1	103	354	48.1	38.3	84
Gemmeiza 1	4646	13167	35.4	107	316	49.2	43.4	98
Wadi el Neil	4802	13340	36.1	108	426	40.7	43.2	95
Fang 60	4630	12019	38.9	94	460	33.6	42.0	90
Condor	4733	13172	36.4	102	511	34.1	40.5	78
F6bulk [a]	4816	13700	35.2	108	425	42.0	39.1	92
12300 [b]	4747	14116	33.7	107	467	35.9	41.0	91
145F6 [c]	4583	13507	34.2	108	438	35.9	40.5	90
El Neilain	4800	13637	35.3	108	413	40.6	45.9	101
Late planting date (15 December)								
Seri 82	3509	10013	34.7	99	352	47.5	33.0	80
HD2380	4000	10869	36.3	94	400	32.1	44.5	83
Nacozari	3743	10395	35.7	93	355	42.0	34.5	80
Glennson	3326	10561	31.4	98	375	42.1	31.5	84
Giza 165	3319	10118	32.6	101	300	45.4	35.8	87
Debeira	3497	10591	32.9	101	363	38.7	35.3	84
Genaro 81	3394	10311	32.9	98	341	45.7	31.4	76
Gemmeiza 1	3274	9983	32.6	100	288	45.8	35.7	89
Wadi el Neil	3308	10291	32.0	101	372	37.5	36.2	85
Fang 60	3744	10376	35.9	92	352	39.2	35.8	86
Condor	3793	10716	35.2	98	445	35.2	33.9	74
F6bulk [a]	3068	10339	29.7	100	404	39.8	31.2	83
12300 [b]	3114	10458	29.4	100	397	35.5	33.3	85
145F6 [c]	3335	10611	31.3	101	400	34.6	32.6	83
El Neilain	3335	10236	32.5	100	362	37.7	39.2	90
Effect	**	***	NS	***	*	***	***	***
SE±	116	201	0.85	0.5	15	0.86	0.49	1.0
C.V.(%)	8.5%	5.1%	7.4%	1.4%	11.7%	6.4%	3.8%	3.4%

a = F6bulk L.2606-90/91; b = 12300X14PYTV(NH243); and c = 145F6-79/80X14PYTV(NH248).
*, **, *** = Significant at 5, 1 and 0.1% probability levels, respectively.
NS = Not significant.
OPT = Optimum planting time and LPT = Late planting time.

Table 3. Mean grain yield (kg/ha) of elite wheat genotypes as influenced by planting date in the three growing seasons (1995/96-1997/98) at the Hudeiba Research Farm.

Genotype	Optimum planting date (15 Nov.)			Late planting date (15 Dec.)		
	95/96	96/97	97/98	95/96	96/97	97/98
Seri 82	5079	4202	5673	2707	3681	4139
HD2380	5089	4151	5541	2988	3909	5103
Nacozari	4514	4139	5387	2917	3606	4707
Glennson	4377	4318	5313	2941	3040	3995
Giza 165	4292	4332	5340	2796	3068	4092
Debeira	4535	4536	5543	3009	3195	4286
Genaro 81	4759	4481	4898	2997	3515	3670
Gemmeiza 1	4361	4434	5143	2669	3261	3891
Wadi el Neil	4462	4557	5386	3209	2656	4058
Fang 60	4850	3927	5114	2966	3582	4683
Condor	4638	4479	5082	2968	3755	4657
F6bulk [a]	4574	4479	5395	2768	2902	3534
12300 [b]	4353	4842	5046	2416	2950	3976
145F6 [c]	4494	4535	4719	2889	3052	4064
El Neilain	4721	4421	5257	2983	3287	3737
Effect	**					
SE±	202					
C.V.(%)	8.5					

a = F6bulk L.2606-90/91; b = 12300X14PYTV(NH243); and c = 145F6-79/80X14PYTV(NH248).
*, **, *** = Significant at 5,1 and 0.1% probability levels, respectively.
NS = Not significant.

FIELD PERFORMANCE OF MIXTURES OF FOUR WHEAT CULTIVARS IN SUDAN

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ABSTRACT

Wheat (*Triticum aestivum* L.) genotypic mixtures were studied for two seasons, 1997/1998 and 1999/2000, at the Gezira Research Station, Wad Medani, Sudan. Four agro-morphologically distinct commercial cultivars, viz., Debeira, Condor, Argine and Neilain, were compared with all two-way mixtures in addition to 3:1 and 1:3 ratios of Debeira and Condor. Means for grain yield were significantly different in the first season only. Plant height conferred a high competitive ability upon Neilain, the tallest cultivar, which suppressed admixture genotypes in both seasons. On the contrary, Debeira, being taller than Condor, was a poor competitor in 1Debeira:1Condor and 3Debeira:1Condor mixtures. However, in the second season, the same combinations outyielded all other mixed stands. In the first situation, growth habit, rate and cycle, related to early flowering and maturity of Condor, were probably effective competitive factors. Reversal of mixture performance in the second season could be related to genotype-environment interactions of component cultivars. While 1Argine:1Condor performance was second best amongst mixed stands in the first season, it was the poorest in the second season. 1Debeira:1Argine outyielded all other mixed stands, was second best among all treatments in the first season, and ranked third in second season. The mixture outyielded its component genotypes in both seasons. Although the increase in Debeira grain yield more than compensated for the loss in Argine, complementary competition was indicated.

INTRODUCTION

Previous studies on intergenotypic mixtures of self pollinated cereal crops indicated a better yield performance and stability over the performance of component genotypes in pure stand. Usually the mixture outyielded its components mid-monoculture but not the highest yielding component in pure stand (Sharma and Prasad, 1978). Mixture performance depends on the interactions and competitive effects between the component genotypes. Schutz *et al.* (1968) developed a model applicable to completely homozygous, self-fertilizing crops when grown in mixtures and identified the following types of interactions:

- Neutral, absence of competitive effects,
- Complementary, gain in one genotype is offset by the loss in the other,
- Over compensatory, mutual advantageous combination i.e. significant increase in mixture performance,
- Under compensatory, disadvantageous combination i.e. lower performance of mixture.

High temperature is the main wheat production constraint in the Sudan where the winter is short and warm. The use of intergenotypic mixtures may modify the micro-environment of the wheat crop through differences in leafiness, height and tillering ability. In an alternative attempt to increase productivity and yield stability, studies on intergenotypic mixtures were conducted under Sudan's 'unique' wheat growth environment. The objectives were to study the interactions of varietal mixtures and identify high-yielding harmonious combinations, if possible.

MATERIALS AND METHODS

Four agro-morphologically distinct commercial bread wheat cultivars were used in this study:

- Neilain (N), tallest and early in heading and latest in maturity;
- Debeira, second tallest and mid-early in heading and maturity;
- Argine (A), third shortest and latest in heading and with mid-maturity;
- Condor (C), shortest and earliest in heading and maturity.

In addition, 1:1 binary mixtures of all genotypes were studied. In addition, Debeira and Condor were studied in 3:1 and 1:3 mixed stands. Mixing of genotypes was calculated on basis of seed number. The experiment comprised of twelve treatments: four pure stands, six 1:1 binary mixed stands and two 3:1 and 1:3 mixtures of Debeira and Condor. The twelve treatments were arranged in a randomized complete-block design with 4 replications. Each treatment was sown in 16 rows, 5 m long and 0.2 m apart. The experiment was conducted for two seasons, 1997-98 and 1999-2000, at Gezira Research Station, Wad Medani, Sudan (14° 24'N 33° 38'E 400 m a.s.l. The experiment was planted during the 4th week of November at a seeding rate of 100 kg ha^{-1}. Nitrogen and phosphorus fertilizer were applied at sowing at the rate of 86 kg N ha^{-1} and 43 kg P ha^{-1}. Sowing seeds were treated with Gaucho for controlling both termites and aphids. The experiment was irrigated every 2 weeks and hand-weeded. Measured characters included flowering, maturity, plant height, productive tillers (number of spikes m^{-2}), kernels spike^{-1}, thousand kernel weight and grain yield. Component cultivars in mixed stands were separated according to spike type. The results for each season were analyzed for differences. According to De Wit and Van der Bergh (1965), the following calculations was made:

Yielding ability (%) = (Ymix/Ymono)/100
Relative yield total = ½ [(Yab mix/Yaa mono) + (Yba mix/Ybb mono)]
Mean relative yield (%) = (Ymix/Ymid-mono)/100

Where,

Yab mix = yield of genotype a (kg ha^{-1}) in mixed stand with genotype b;
Yaa mono = pure stand yield (kg ha^{-1}) of genotype a;
Yba mix = yield (kg ha^{-1}) of genotype b in mixed stand with genotype a;
Ybb mono = pure stand yield (kg ha^{-1}) of genotype b;
Ymix = yield (kg ha^{-1}) of mixed stand;
Ymono = pure stand yield (kg ha^{-1}) of higher yielding genotype; and
Ymix-monoculture yield (kg ha^{-1}) = (Yaa mono + Ybb mono)/2

Competitive ability = percent grain or loss of a genotype in mixed stand relative to its pure stand yield (kg ha^{-1}).

RESULTS AND DISCUSSION

The mean performance of the treatments for grain yield is presented in Table 1. Means for the first season were associated with significant differences (P 0.05) and means for the second season were all similar. In the first season, Neilain performance in pure stand outyielded all treatments, 1D:1A ranked second, followed by Debeira pure stand, 1A:1C mixture and Argine pure stand. 1D:1A combination outyielded its component genotypes pure stand with 101.88 yielding ability, 1.07 relative yield total and 102.77 mean relative yield (Table 2). Although the increase in Debeira performance was more, +6.88, than the decrease in Argine performance, -1.41 (Table 3), complementary competitive effects were indicated. A similar trend of mixture performance was demonstrated by 1A:1C with 100.66 yielding ability, 1.01 relative yield total and 100.84 mean relative yield. In this combination, Argine was more competitive, 2.76, than Condor, -1.07. The performance of D:C genotypic mixtures, especially in 1D:1C and 3D:1C mixed stands, was modest. Debeira performance in the two mixed stands was significantly inferior to its performance in pure stand. Debeira, though taller, was less competitive, -17.75, with shorter Condor, 2.76, and plant height had no competitive advantage. Other factors such as growth habit, growth rate and cycle, early flowering and maturity may have been involved. Sage (1971) studied the behavior of mixtures of wheat cultivars having wide phenotypic differences and found that height and earliness in maturity were strong competitive characters. The performance of Neilain in association with the other 3 cultivars, Debeira, Argine and Condor was unharmonious, indicating under compensatory competition. Neilain, being taller, suppressed its component cultivars in mixed stands. In this situation, plant height conferred high competitive ability.

Since the means of the treatments for the second season were not significantly different, our discussion will consider the general trend of the performance of the treatments. Three genotypic mixtures, 1D:1C, 3D:1C and 1D:1A outyielded all other treatments. Argine was the leading cultivar in pure stand. Three genotypic mixtures, 1A:1C, 1D:1N and 1D:3C indicated lower performance than the performance of component genotypes in pure stand. These included 1A:1C which was second best mixed stand in first season. Of interest is the good performance of 1D:1C and 3D:1C mixed stand in this season. At this point there is no possible explanation for this change in the performance of the two mixtures except for genotype-environment interactions.

Based on these results 1D:1A genotypic mixture only demonstrated harmonious performance in the two seasons.

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Questions and Answers:

Sewalem Amogne: What is the reason for 1Debeira:1Argine to ranking first in the first season but third in the second season in terms of grain yield?

Answer: This was attributed to genotype by environment interaction. 1999-00 season encountered high temperature during the season or late season and adversely affected both genotypes.

Sewalem Amogne: Do you think it is logical to mix early- and late-maturing varieties together? There will be a problem of harvesting.

Answer: Maturity differences are not that big – 5-8 days. Early and late maturity can tolerate early-season and late-season heat stress better.

Vicki Tolmay: Do farmers and "end users" find the mixtures acceptable?

Answer: This is a question that we are raising and since our wheat varieties are more or less similar in maturity and quality we expect acceptance. We have to have an answer to this question.

Table 1. Means for yield (kg/ha) of pure and mixed stands.

Treatment	Season	
	1997-98	1999-2000
Debeira	4478 AB	4069
Condor	4385 AB	4000
Argine	4401 AB	4203
Neilain	4921 A	4160
Debeira:Condor 1:1	3876 B	4366
Debeira:Argine 1:1	4562 AB	4213
Debeira:Neilain 1:1	4398 AB	3933
Argine:Condor 1:1	4430 AB	3803
Argine:Neilain 1:1	4128 AB	4177
Condor:Neilain 1:1	4216 AB	4041
Debeira:Condor 3:1	4009 B	4210
Debeira:Condor 1:3	4218 AB	3953
S.E. ±	248	

Means within the same column having the same letter(s) are not significantly different at the 5% level of the LSD test.

Table 2. Yielding ability (%), relative yield total and mean relative yield of mixed stands.

Mixed stand	Yielding ability (%)		Relative yield total		Mean relative yield (%)	
	1997-98	1999-00	1997-98	1999-00	1997-98	1999-00
1D:1C	86.56	107.30	0.871	1.09	87.47	108.20
1D:1A	101.88	100.20	1.027	1.030	102.77	101.90
1D:1N	89.45	94.50	0.940	0.95	93.57	95.80
1A:1C	100.66	90.90	1.008	0.93	100.84	92.70
1A:1N	83.88	99.40	0.923	1.00	88.57	99.90
1C:1N	85.88	97.0	0.928	0.99	90.50	99.00
3D:1C	89.45	104.8	1.007	1.41	90.39	105.70
1D:3C	94.18	97.2	0.948	0.90	95.17	98.00

Table 3. Competitive ability of genotypes; percent gains (+) or losses (-) as compared to pure stand, 1996-97.

Associate producer	Debeira	Condor	Argine	Neilain
Debeira	0.000	-17.75	+6.88	-3.22
Condor	+6.50	0.00	-1.07	-17.67
Argine	-1.41	+2.76	0.00	-24.14
Neilain	-8.99	+8.74	+3.33	0.00

THE ASSESSMENT AND SIGNIFICANCE OF PATHOGENIC VARIABILITY IN *PUCCINIA STRIIFORMIS* IN BREEDING FOR RESISTANCE TO STRIPE (YELLOW) RUST: AUSTRALIAN AND INTERNATIONAL STUDIES

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ABSTRACT

Stripe (yellow) rust, caused by *Puccinia striiformis*, continues to cause crop losses in several regions of the world. National and international control strategies focussing on breeding resistant cultivars are dependent on relevant information concerning the nature and extent of pathogenic variation. Detailed studies in Australia have shown a progressive evolution of pathotypes which have, in some instances, led to epidemics and caused significant problems for commercial wheat production. Recent changes in the pathogen population have caused potential problems for the barley industry. While studies have been undertaken in certain locations for varying periods of time, the continuing need for specialist facilities, experienced staff and common differential testers has generally resulted in discontinuous data sets. In order to overcome these difficulties, and provide a basis for regular data collection, a simplified method based on field assessment of near isogenic lines (NILs) has been evaluated in several international locations. The NILs, which are based on a selection of the susceptible spring wheat cultivar Avocet, have allowed the effectiveness of a range of single resistance genes to be determined. Data arising from this international project has provided evidence for regional differences in pathogenic variability between populations of *P. striiformis* f.sp. *tritici*. For example virulence for *Yr1* was common in the eastern districts of Central Asia, China and certain locations in India. However, virulence for *Yr9* was more widespread in diverse locations including the Middle East (Iraq, Turkey, Syria), China, Africa (Uganda), Australasia (New Zealand) and South and Central America (Chile, Ecuador, Mexico). Avirulence for certain genes, including *Yr5, Yr15* and *Yr18*, suggests potential usefulness of these genes in breeding programs. However, virulence for the former two resistance genes reported elsewhere would preclude their adoption in some breeding programs. The paper will describe these studies, and discuss the use of the data in breeding programs aimed at the release of stripe rust resistant wheats.

INTRODUCTION

Stripe or yellow rust, caused by *Puccinia striiformis* Westend., has traditionally been associated with cereal production in the cool, temperate regions of the world including the Americas, Europe, Asia, the Middle East, Central and South East Asia, Russia, China and East and Central Africa. These environments, which may include a large array of latitude and

elevation combinations, are generally characterized by varying periods of cool temperature (0 ^{0}C to 15^{0}C) and high humidity in the crop canopy which are necessary for infection and disease development. Where these environmental conditions coincide with available pathogen inoculum and susceptible host material, including specific cereal and grass genera, stripe rust epidemics of varying intensity and duration may develop.

The introduction of the stripe rust pathogen to certain new areas that were environmentally conducive to epidemic development has resulted in significant national issues over the past 20 years. This progressive extension of the geographical distribution of stripe rust has served to highlight the important influence that human transport assumes in global plant disease epidemiology. The following incidents illustrate this principle:

1. The discovery of barley stripe rust in Central America in 1975 (Dubin and Stubbs, 1986) and subsequently North America in 1991 (Marshall and Sutton, 1995). The evidence suggests that the introduction to Colombia (Central America) originated from Europe, whereas the detection in Mexico was thought to be related to travel by people undertaking clandestine activities from Central America (H.J. Dubin, pers. comm.).

2. The first report of wheat stripe rust in Australia in 1979 was suggested to be due to contaminated clothing on international air travelers from Europe (Wellings *et al*, 1988). The authors provided evidence including spore survival and common features between stripe rust detected in the initial outbreak in Australia and those of the contemporary pathogen population in southern Europe.

3. The first detection of wheat stripe rust in South Africa was reported in 1996 (Pretorius *et al.*, 1997). Initial isolates appeared to be phenotypically similar to pathogen characteristics known in the Middle East, and hence human transport may again be implicated.

The significance of unique pathogen isolates introduced into newly defined geographical regions, referred to in this paper as exotic introductions, can only be determined on the basis of current knowledge of pathogen populations in those particular regions. The availability of this background data can be critical in allowing a basis for predicting the expected contemporary impact of such introductions, and provide the possibility of introducing control strategies, such as importing resistant cultivars and introducing diverse resistances to breeding programs.

Recurrent stripe rust epidemics have occurred throughout the Middle East, West Asia and Pakistan during the 1990s and more recently in the Central Asian republics over the past several years. These epidemics were associated with the widespread deployment of cultivars previously protected by the resistance gene *Yr9*. In these regions where the magnitude of pathogen inoculum has dramatically increased, the opportunities for further pathogenic evolution have also escalated and thereby assumed a potential threat to the deployment of current and future resistant cultivars.

Our objectives in this paper are to review factors governing the nature and importance of pathogen variability in the context of cultivar development and deployment. Examples will be drawn from Australian and international studies which have been directed at methodologies for monitoring pathogenic change in *P. striiformis* populations.

Factors Influencing Pathogenic Variability in *P. striiformis*

It is convenient to consider two broad areas of pathogenic variation that have been observed in the capacity of this pathogen to cause disease. These can be conveniently regarded as specialization between hosts, and specialization within hosts. The former is that specialization that has been noted between various host genera in their respective capabilities to support the growth and survival of pathogen isolates. The International Code of Botanical Nomenclature recognizes the taxonomic unit of *forma speeialis* (literally "special form") to describe this variation which was first reported for *P. striiformis* in Europe by Eriksson and Henning in 1894. Although this concept has been widely appreciated, there remain several areas of contention which are important in understanding global variation in *P. striiformis*.

In addition to differences in host range, further levels of specialization within defined collections of certain hosts were observed in the USA for the wheat stem rust pathogen (*P. graminis* Pers. f. sp. *tritici*) by Stakman and colleagues in 1917, and later in *P. striiformis* by Allison and Isenbeck (1930) in Europe. This second level of specialization within hosts has been variously termed biologic form, physiologic race, strain or pathotype.

1. *Formae speciales* in *P. striiformis*

Since the initial work of Eriksson in 1894 and subsequent contributions in the early twentieth century, a corpus of research accumulated in an attempt to describe the limits of host range variability within *P. striiformis*. The following represents an attempt to draw conclusions from this work:

P. striiformis* f. sp. *tritici (Eriksson, 1894; *Pst*), the pathogen of wheat stripe (yellow) rust, has a host range which is predominantly wheat, but also includes certain barley, rye and triticale genotypes. Other hosts include the weedy grasses encompassing species within the *Hordeum*, *Agropyron*, *Phalaris*, *Hystrix* and *Bromus* genera (Hungerford and Owen, 1923; Zadoks, 1961; Holmes and Dennis, 1985).

P. striiformis* f. sp. *hordei (Eriksson, 1894; *Psh*), the pathogen of barley stripe rust, principally infects barley although it has also been reported to cause disease on certain wheats (Stubbs, 1985). The host range has also been noted to include weedy grasses, in particular *Hordeum murinum* (Zadoks, 1961) and *H. jubatum* and *H. leporinum* (Marshall and Sutton, 1995).

P. striiformis* f. sp. *dactylidis (Manners, 1960). Stripe rust infecting cocksfoot (*Dactylis glomerata*) was originally described as morphologically distinctive in urediospore size and therefore ascribed the status of variety within *P. striiformis* (Manners, 1960). However, the consensus of opinion leads to the conclusion that this pathogen is best regarded as a distinct *forma specialis* (Tollenaar, 1967; Latch, 1976). The host: pathogen association is very close, so that pathogen isolates collected from cocksfoot cannot infect cultivated cereals and grasses, or *vice versa*. The optimum temperature for urediospore germination was noted to be 21-24^{0}C (Manners, 1960), in contrast to 6^{0}C for *Pst* (Tollenaar, 1967).

P. striiformis* f. sp. *poae (Tollenar, 1967) was described as the pathogen causing stripe rust of Kentucky bluegrass (*Poa pratensis*). Temperature optima for urediospore germination (12-18^{0}C) and the close association between pathogen isolates and the host suggest that this is a

distinctive *forma specialis*, although the geographic distribution outside the USA remains unclear.

A potentially new form of *P. striiformis* was described in Australia by Wellings *et al.* (2000). The pathogen was closely associated with weedy *Hordeum* species, showed broad avirulence on the wheat differential testers and appeared to contrast at one isozyme locus with *Pst*. The pathogen, temporarily referred to as barley grass stripe rust (BGYR), was observed to cause disease on certain barley cultivars naturally infected in the field.

2. Pathotype variation within *P. striiformis* f. sp. *tritici*

Pathotype variability has traditionally been studied using defined sets of host genotypes inoculated with pathogen isolates in controlled environments. Such studies have almost entirely focussed on greenhouse testing of seedling plants and, when most effective, have attempted to relate the results to resistance genes deployed in commercial agriculture. The various sets of differential genotypes employed in the study of *Pst* were reviewed by McIntosh *et al.*, (1995). The set of Johnson *et al.* (1972), as modified by Wellings and McIntosh (1990), have been used for continuing studies of pathotype variability in the cereal rust laboratory at PBI Cobbitty since the first introduction of *Pst* to Australia in 1979. During this period, pathotype evolution arising from progressive single step mutation has resulted in the detection of over twenty variants. The results are summarized in Figures 1 and 2. While the majority of new pathotypes have represented a progressive increase in virulence, several reversions to avirulence have also been detected. With the exception of pathotype 64 E1 A-, all new pathotypes have only varied by one gene for virulence compared to a previously detected pathotype. On the basis of these observations, it can be concluded that there has been no evidence of further exotic introduction of *Pst* into Australia.

Similar studies of *Pst* have been conducted by various groups around the world. The most notable contribution was that of the late R.W. Stubbs at the Research Institute for Plant Protection (IPO), Wageningen, The Netherlands. Although Stubbs work was focussed on Europe, he was able to accept *Pst* isolates from around the world under an agreement with CIMMYT, and so was able to gain some insight into global variability. Investigations of recent stripe rust epidemics in Central Asia discovered that The Institute of Genetics, Tashkent, Uzbekistan, has conducted similar *Pst* surveys for the former Soviet Union over many years, although the data has remained essentially unavailable to the Western scientific community.

As a result of the recurring epidemics noted in the above regions, and in the absence of a consistent monitoring program for pathotype change in *Pst* over large areas of the world's wheat growing areas, an alternative method employing near isogenic lines in trap nurseries is being evaluated. This has become a joint project between CIMMYT, ICARDA and PBI Cobbitty, with some funding provided by the Australian Center for International Agricultural Research. The method provides advantages in being less reliant on specialist facilities and expertise, and can potentially sample pathogen populations over the period that the nursery remains viable in the field.

The nurseries distributed as four cohorts have resulted in the collection of 58 data sets. Several of these collections represent multiple observations across several years at a single site. Low disease responses on the recurrent parent Avocet S has indicated poor and uneven infection or the presence of highly avirulent pathotypes at several sites. In these situations

where Avocet S showed responses of less than 40S, the data sets were regarded as difficult to interpret and hence were not considered in the analysis. The following represents a summary of current results.

1.General Trends: The data indicate that pathogen populations show dynamic change in several dimensions. Firstly, variability at a single site is illustrated in Table 1 where virulence for *YrA* was present in 1996 at Tel Hadya, Syria, but absent in subsequent years. It is possible that *YrA* could be selected in breeding populations at this site, despite the widespread ineffectiveness of this gene in most regions.

Secondly, the data provide evidence that the pathogen population may vary within countries. The data in Table 2 indicate that variation for virulence for *YrA* occurs at sites within New Zealand and Turkey. The progressive accumulation of such data will be helpful in predicting cultivar response at certain locations within countries.

Thirdly, there was evident pathogen variability across regions. The data in Table 3 indicates that variation for *Yr1* enabled some distinction between the pathogen population in eastern Europe (i.e., west of the Caspian Sea) and Central Asia, and between countries in South America and the Indian subcontinent. Although these data sets are limited, the early evidence suggests that distinctions in pathogen populations may give understanding in the large scale movements of new virulence combinations, and hence allow some early prediction of potential problems with cultivars carrying known resistance genes.

2. Comments on Specific Resistance Genes: It is evident that several genes were broadly ineffective in providing cultivar resistance. The *Yr9* gene has been widely deployed and the responses of a large group of *Yr9*-cultivars related to Seri 82 have received considerable publicity in many regions where the pathogen population acquired virulence. However, the NIL data indicate that *Yr9* remained effective at sites in India, China, South Africa and Australia. Similarly, the resistance genes *Yr6*, *Yr7* and *YrA* were broadly ineffective although they appeared to provide protection at some sites.

Virulence for *Yr8* has generally been associated with the Middle East region, although the only clear data to confirm this was obtained from Adana (Turkey), Almaty (Kazakhstan) and Bajaura (India). This resistance gene has not been deployed in cultivars and hence any variation must be due to factors other than selection. Virulence for *Yr17* appeared to be rare, although Carillanca (Chile), Greytown (South Africa), Sichuan (China) and possibly Almaty (Kazakhstan) showed distinctly high responses on the *Yr17* NIL. The response of the adult plant resistance gene *Yr11* was variable, ranging from R to 70 MS. However, it could not be concluded that virulence for *Yr11* was evident at these sites.

The resistance genes *Yr5*, *Yr10*, *Yr15* and *Yr18* were concluded to be effective at all sites. The response of *Yr18* was variable, ranging from R in the *Yr18* NIL to 80MS in the Jupateco R line depending on site and year.

CONCLUSIONS

Sources of resistance to stripe rust are not difficult to find and exploit in breeding programs which aim to select and release resistant cultivars. The issues of disease control through breeding will pre-eminently focus on resistance durability which, in the case of the cereal

rusts in general, will be a function of genetic variation in characters determining pathogenicity.

The development and deployment of trap nurseries utilizing isogenic lines for the assessment of pathogenic variation in *P. striiformis* offers several advantages. Field nurseries are relatively convenient to establish and monitor provided the materials are well adapted agronomically, and that the size of the nursery maintains a balance between numbers of entries and efficiency in monitoring resistances of economic importance. If these parameters are kept in view, the NIL nursery will provide a cost-effective means of pathogenicity assessment by removing reliance on sample collection, multiplication and processing through expensive environmentally controlled greenhouses. Such facilities are usually not available in developing countries.

However problem areas will need to be addressed in order to overcome certain inefficiencies:

1. Gene combinations in the NILs will allow the identification of certain virulence combinations in pathogen populations which cannot be detected with the current stocks. These combinations will also assist in the detection of pathotype mixtures which would be expected to occur on occasion in naturally infected nurseries. Further genes will need to be transferred to Avocet S in order to allow a complete array of testers for international monitoring. Initiatives have been taken to address these issues.

2. Data collection and dispatch is currently sporadic and greater attention is required to have co-operators return data promptly in order to maintain a contemporary brief on pathogen change.

3. The *Yr12* and *Yr17* NILs have been shown to be identical, with the former concluded to be incorrect based on paired seedling tests with *Yr17* avirulent/virulent cultures. While this error has served as a check in nursery data, it also provides a reminder in regard to the difficulties of identifying error in NIL development.

4. The morphological similarity of NILs will mean that authentication of line integrity will be limited by the pathogen cultures available to the developer. Linked markers, such as brown chaff and *Yr10*, can be useful in certain circumstances.

Despite several shortcomings, the NIL set for monitoring *P. striiformis* has shown sufficient potential to warrant further development of the set, and the continued deployment of nurseries at a range of international locations. The direction of the project must continue to be founded on direct links to breeding programs aiming to deliver stripe rust resistant cultivars. If these links are not maintained, the project risks irrelevance. However, the concerted commitment of pathology and breeding groups will facilitate the development and monitoring of resistances in order to capture the long term benefits of disease control for farming communities.

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Questions and Answers:

Cobus le Roux: Are you able to distinguish between different biotypes by using the isogenic Avocet lines in the trap nurseries?

Answer: The trap nurseries with Avocet NILs are designed to evaluate the effectiveness of single genes. It can be expected that nurseries will be infected with one or more pathotypes. As gene combinations in NILs become available, it will be feasible to distinguish pathotype mixtures in nurseries. It is also anticipated that the NIL set will form the basis for a revision of pathotype nomenclature in *Puccinia striiformis* f.sp. *tritici*.

M.A. Mahir: What is the possibility of hybridization and recombination between pathotypes being responsible for the continuous development of new pathotypes and biotypes of YR beside genetic mutation?

Answer: Somatic recombination between cereal rust pathotypes has been clearly documented in Australia for wheat stem rust (*P. graminis tritici*) and rye stem rust (*P. graminis secalis*) giving rise to hybrid stem rust pathotypes. The literature also suggests somatic recombinants for *P. striiformis*. However, the evidence for *P. striiformis* in Australia does not support somatic recombination at the present time.

Temam Hussien: How often do you find new pathotypes of yellow rust in Australia? In other words, what is the rate of mutation of Yr of wheat?

Answer: It is difficult to predict a precise mutation rate, since this will be a function of population size and selection pressure. Nevertheless, it appears on average that we can expect a new pathotype each year, although most of these pathotypes have not been significant for our commercial wheats.

Temam Hussien: You mentioned "step-wise mutation" as one of the causes of variability in yellow rust of wheat. What do you mean by step-wise mutation?

Answer: The detection of a new pathotype has always been linked to a pre-existing pathotype, with the only difference being a single gene for virulence. The simplest explanation is that genes for virulence are mutating one at a time and give rise to a new, but closely related, pathotype. Historically, this has occurred for one gene at a time, usually for increased virulence and occasionally for loss of virulence, and hence the term "step-wise".

Figure 1. **Progressive emergence of new pathotypes of *P. striiformis* f. sp. *tritici* in relation to previously detected pathotypes for the period 1979 to 1988 in Australia.**

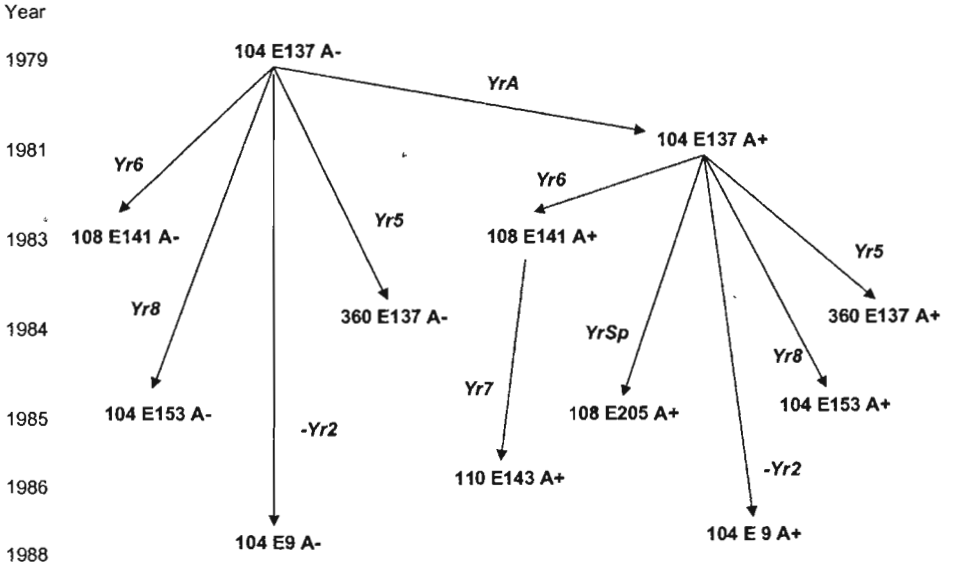

Figure 2. **Progressive emergence of new pathotypes of *P. striiformis* f. sp. *tritici* in relation to previously detected pathotypes for the period 1992 to 1999 in Australia.**

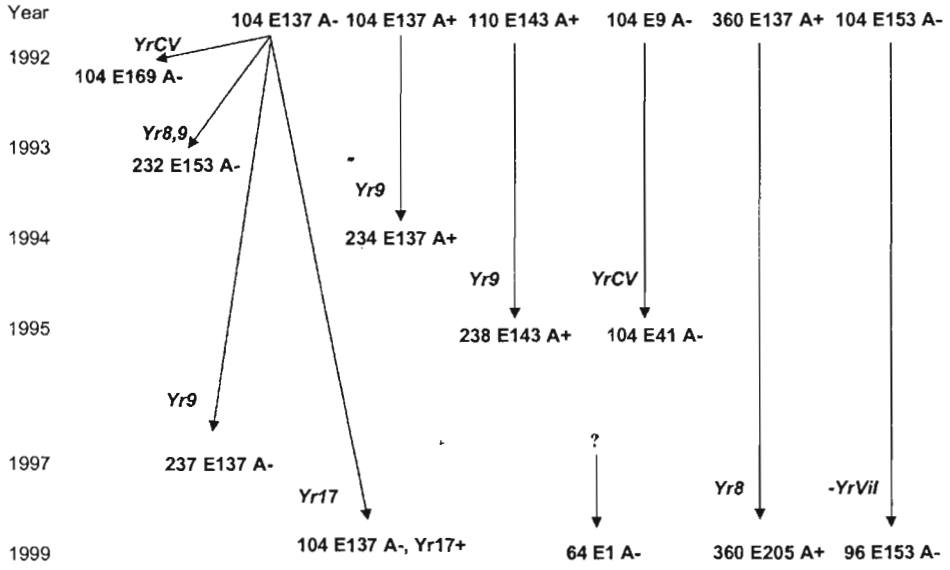

Table 1. **Variation in stripe rust response at the ICARDA breeding plots, Tel Hadya Syria, for NILs contrasting for *YrA* in the period 1997 to 1999.**

Year of Assessment	Avocet R (YrA)	Avocet S
1996	90S	95S
1997	5R	95S
1998	5R	95S
1999	5R	100S

Table 2. **Disease response variation for NILs contrasting for *YrA* and grown at different sites in New Zealand and Turkey in 1998.**

Location	Avocet R (YrA)	Avocet S
New Zealand:		
Lincoln	80S	60S
Aorangi	R	100S
Gore	80S	80S
Turkey:		
Gissar	R	80S
Adana	100S	100S
Izmir	100S	100S
Ankara	90S	90S

Table 3. **Stripe rust disease responses of NILs contrasting for *Yr1* in several regional locations.**

Location	Yr1 NIL	Avocet S
Eastern Europe:		
Ankara, Turkey	R	90S
Apsheron, Azerbaijan	R	100S
Central Asia:		
Almaty, Kazakhstan	40	80
Sichuan, China	40S	80S
South America:		
Santa Catalina, Ecuador	R	90S
Quilamapu, Chile	50S	90S
Indian Subcontinent:		
Ludhiana, India	60S	80S
Kavre, Nepal	R	80MS-S
Islamabad, Pakistan	R	40S

SOURCES AND GENETIC BASIS OF VARIABILITY OF MAJOR AND MINOR GENES FOR YELLOW RUST RESISTANCE IN CIMMYT WHEATS

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ABSTRACT

Twenty-seven race-specific genes that confer resistance to yellow rust (*Puccinia striiformis*) have been catalogued so far. Of these genes, *Yr1, Yr3, Yr15, Yr17* and *Yr27* have conferred high levels of resistance to some CIMMYT wheats either singly or in combination with *Yr9* to current pathogen populations globally. We have detected the presence of additional, possibly new, genes in recent CIMMYT wheat lines. These major genes can be traced to the following sources: 'Bobwhite', 'Weaver', Chinese and synthetic wheats. The resistance gene from Bobwhite confers a seedling infection type ranging between 3 and 5 (on a 0-9 scale) and is present in several advanced lines through the Bobwhite derived line 'Pastor'. Weaver's seedling resistance is associated with a gene that displays seedling infection types ranging from 4 to 6; whereas seedling reactions of the Chinese and synthetic wheats derived advanced lines indicate that they may have contributed at least 4 new genes. A high degree of genetic diversity for additive, minor genes also exists in CIMMYT germplasm. Genetic analyses of wheat lines showing high levels of adult-plant resistance in evaluations conducted recently in Mexico, Ecuador, Kenya, Uganda and Iran indicate the presence of at least 4 to 5 additive, minor genes in each line. Utilization of resistance based on minor genes should lead to resistance durability.

INTRODUCTION

Yellow (or stripe) rust, caused by *Puccinia striiformis tritici*, is an important disease of wheat in most wheat growing regions including Africa. Using resistant cultivar for disease control is the best strategy as it has no cost to the farmer and is environmentally safe. Historically, race-specific major genes have been used to breed resistant cultivar. At present, 30 genes are catalogued (McIntosh *et al.*, 1998). A majority of these are race-specific in nature and virulence has been identified for several of them at least somewhere in the world. Some important cultivars where resistance is based on a single race-specific gene, or combinations of two of them, are currently grown on a large area in countries where yellow rust has posed major losses or threats in the past years. Resistances of Inquilab 92 based on *Yr27* and PBW343 based on the combination of *Yr3* and *Yr9* are highly vulnerable as they are the most important cultivars in northwestern Pakistan and India, respectively, and virulences for these genes and their combinations are known. These cultivars show unacceptable levels of adult plant resistance in Mexico when tested with a race virulent on the above genes. Similarly, a number of Kauz derived varieties, e.g. Bakhtawar 94 (Pakistan), WH542 (India), Memof (Syria), Basribey 95 and Seyhan 95 (Turkey) and Atrak (Iran), were released following the

widespread epidemic in these countries on Veery#5 derived cultivars. Immunity of Kauz in these countries is due to the presence of the combination of *Yr9* and *Yr27*. Combination of virulences for these two genes in the yellow rust population do not exist at present in the above countries, however, is known to occur in Mexico. Slow rusting gene *Yr18*, also present in Kauz, does not confer enough protection under high disease pressure (Ma and Singh 1996) and hence Kauz shows unacceptable disease levels when tested in Mexico. This kind of information on the genetic basis of resistance could be extremely useful for a country to prepare for a forthcoming epidemic and take all measures to diversify the crop by promoting additional genetically diverse cultivars. One of the main objectives of CIMMYT's wheat genetics and breeding programs is to generate diverse germplasm. We thrive to achieve resistance durability by combing genes that have small to intermediate but additive effects. The magnitude of genetic diversity that exists in the CIMMYT germplasm with respect to genes conferring race-specific and durable resistance is reported in this paper.

MATERIALS AND METHODS

Wheat lines reported for genetic diversity of race-specific genes (Table 1) were identified after testing over 2000 new lines that are currently being distributed through various screening nurseries from CIMMYT. These lines were evaluated in the seedling growth stage with Mexican *P. striiformis tritici* pathotype Mex 96.11 that has following avirulence/ virulence formula: *Yr1, 4, 5, 8, 15, 17/ 2, 3, 6, 7, 9, 10, 27* based on the near-isogenic Avocet lines. Some reported genes could be identified by further testing of these lines with additional races and through the use of pedigree analysis. The lines were also evaluated in the field at CIMMYT's research station near Toluca, Mexico State during different years. The 0-9 infection type scale used for seedling evaluation is described in Roelfs *et al.* (1992). Modified Cobb Scale (Peterson *et al.*, 1948) was used for field evaluation of disease severity and response to infection was characterized as R, MR, MS and S (Roelfs *et al.*, 1992).

The eleven lines (Table 2) included for genetic analysis have shown high levels of adult plant resistance in field trials at Mexico, Ecuador, Kenya and Iran. These lines show seedling susceptibility in Mexico and Iran and therefore the field resistance observed at least in Mexico and Iran must be based on genes that are effective in adult plant stage. The resistant lines were crossed with the yellow rust susceptible parent Avocet S. A total of 298 eight F_3 lines were obtained for each of the cross by harvesting individual F_2 plants from five F_2 populations derived from individually harvested F_1 plants. About 80 seeds of the F_3 lines and parents were grown in the field at Toluca during crop season 2000 in two 1-m paired row (0.2 m apart) plots on the top of 0.75 m wide raised beds with 0.5 m pathway. Hills of the highly susceptible spreader cultivar Morocco were sown in the middle of the 0.5 m pathway on one side of each plot. Yellow rust epidemic was initiated by inoculating the 4 weeks old spreader rows with a suspension of urediniospores in the light weight mineral oil Soltrol 170. The parents and the F_3 lines were classified for yellow rust for the first time when the flag leaves of the susceptible parent Avocet displayed between 80-100% rust severity. Classification was made two ways: 1) by visually estimating the mean yellow rust severity of the plot, and 2) by classifying each of the line in one of the four segregation categories as given in Table 3 and described in detail by Singh and Rajaram (1992). Some F_3 lines that had disease ratings similar or close to the respective resistant parents were evaluated for a second time about 2 weeks after the first evaluation. By this time disease had further increased on those lines that were different from the resistant parent could be separated from the lines that were truly homozygous for the severity response similar to that of their resistant parent. The χ^2 analysis

was carried out to test whether the observed distribution of F_3 lines was in agreement with the expected ratio.

RESULTS AND DISCUSSION

Possible diversity for race-specific genes present in CIMMYT wheats that are being distributed in the recent years is shown in Table 1. Known genes, such as *Yr1*, *Yr15* and *Yr17* could be identified in some wheat lines. Noteworthy is line Milan that carries gene *Yr17*. This gene is not yet deployed in Africa and is effective to the current population of *P. striiformis*. However, this gene was used extensively in Europe, Australia and New Zealand resulting in the identification of virulent races in the past years in each of the above countries. We can indicate the presence of at least five additional unknown genes in the germplasm that probably have wheat origin. A gene conferring seedling infection type 34 and high level of adult plant resistance is present in wheat lines Pastor, Tinamu, Ducula, etc. and may be derived from some selections of Bobwhite. This gene is effective in Africa and all other sites reporting data on these lines. Its proportion in new CIMMYT lines is increasing due to the use of Pastor in many crosses. Pastor has high yield potential, wide adaptation, excellent industrial quality and resistance to *Septoria tritici* making it an attractive parent in the crosses.

The use of Chinese wheat germplasm to incorporate resistance to head scab has also introduced at least two major yellow rust genes in CIMMYT germplasm. Examples of these CIMMYT lines are some selections of Catbird and SW89.2089/Kauz that have low and moderate seedling resistance but high levels of adult plant resistance (Table 1). CIMMYT lines Weaver and Star appear to carry genes that confer intermediate seedling infection types but moderate and moderately high field reactions, respectively.

Some new genes are also entering in the germplasm from synthetics (Table 1). We recently identified and designated gene *Yr28* (Singh *et al.*, 2000) of *T. tauschii* origin. At least two, or more, additional genes are also present in synthetic derived lines. In all it can be stated that CIMMYT germplasm contains high degree of genetic diversity for race-specific genes that are currently effective in most developing countries. These genes will probably protect some important varieties in the future but eventually succumb to new virulences that will arise in time.

The eleven lines listed in Table 2 display susceptible infection types when tested in Mexico and Iran (data not presented). These lines were purposefully bred to accumulate minor, additive genes for resistance to leaf and yellow rusts and evaluated at selected hot-spot locations under the nursery PCYR/LR (Singh *et al.*, 1999). Lines included for the genetic analysis and listed in Table 2 have shown near-immunity to yellow rust in field trials in Mexico for the last 4 years. In each cross, the distribution of the F_3 lines for disease severity was continuous between the parental severities. Distributions for two crosses are shown in Figures 1 and 2. Only rare F_3 lines showed disease severities similar to the resistant or susceptible parents. The observed continuous distribution indicated that the resistance was complex and was not based on major genes.

The expected proportions of the F_3 lines in four segregation categories, assuming that the resistance is based on 2, 3, 4 and 5 minor additive genes, is given in Table 3. The observed distributions of F_3 lines in 9 of the crosses conformed the ratio expected for segregation of at

least of 4 additive genes (Table 4). Resistance of Chapio and Tukuru was based on the additive interaction of at least 5 minor genes.

All resistant parents included in the genetic analysis are likely to carry the durable slow rusting gene *Yr18* (Singh, 1992; McIntosh, 1992) as they show the linked leaf tip necrosis of adult plants. At least the lines derived from the crosses involving Pavon 76 are also likely to carry minor genes *Yr29* and *Yr30*. These genes are known to be present in Pavon 76 and are very closely linked/ pleiotropic to the genes *Lr46* and *Sr2* that confer durable slow rusting resistance to leaf and stem rusts, respectively. Based on the results from genetic analysis it appears that resistance to yellow rust, approaching near-immunity, can be developed by combining slow rusting genes that have minor/ intermediate but additive effects. The wheat lines listed in Table 4 or 5 should be used in the future crossing program if aim is to achieve high level of minor genes based resistance. Resistance of cultivars carrying such genes should prove to be durable.

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Questions and Answers:

Colin R. Wellings: The F_3 distribution of R x S crosses were presented as a distribution. Were these means for LAI within lines, as one would expect segregation to susceptible in a proportion of the material?

Answer: For the estimation of gene number, we use the four categories (HPTR, HPTS, SegI and SegS). Severity mean of the lines is a useful tool to show the pattern of the distribution of the lines.

Harjit Singh: Since there are a number of examples where slow rusting resistance has been found to be race specific, will it be appropriate to label "slow-rusting" as "race non-specific" as you have done in your presentation?

Answer: In the broad sense, yes! Exceptions can always be found in nature.

Colin Wellings: Given that estimations of additive gene number involve relatively small frequencies of homozygous parental types, do you see any advantage in DH versus RIL populations?

Answer: No, because at CIMMYT we can obtain RILs (Recombinant Inbred Lines, F_5 or F_6) in the same time as one can obtain enough seeds of DH. Ratios are changed only slightly from F_6 to DH.

Colin Wellings (Comment following Ravi Singh's comment): The evidence suggests that virulence to *Yr9* arose in the late 1980s in Ethiopia, and subsequently transferred to the high elevation mountain plateau of Yemen. From there the new rust pathotype survived, and spread to the Nile Valley, Middle East and beyond. These observations would support Dr. Singh's concern.

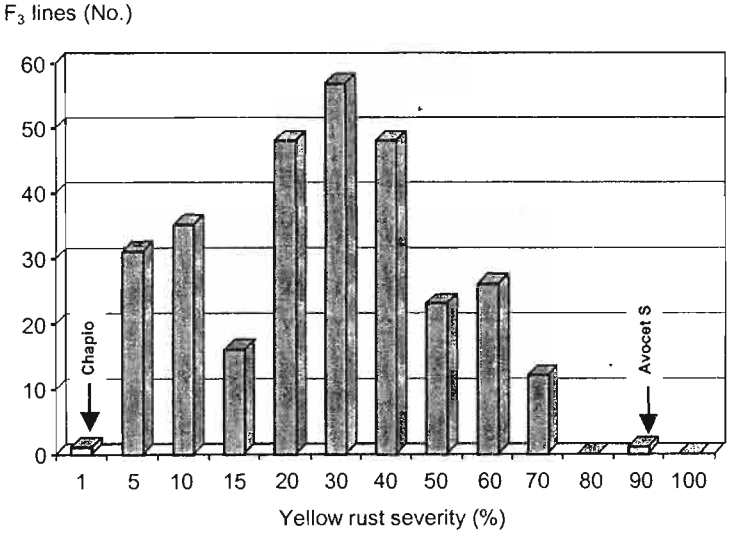

Fig. 1. Distribution of 298 F_3 lines from the cross of susceptible parent Avocet S with resistant parent Chapio

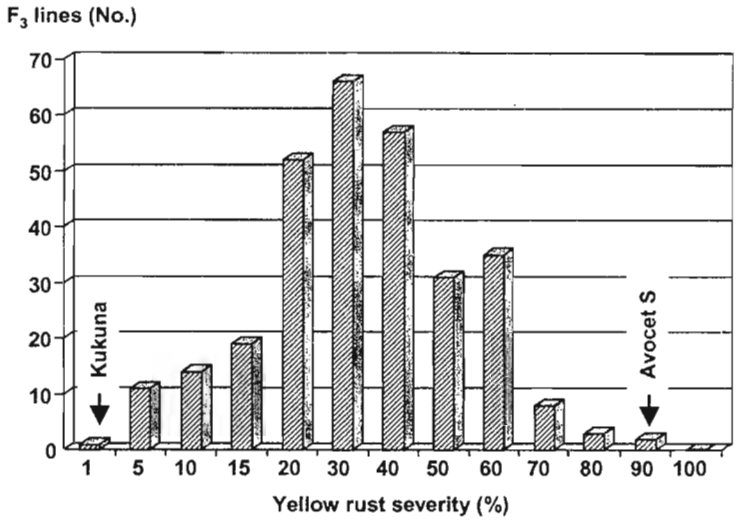

Fig. 2. Distribution of 298 F_3 lines from the cross of susceptible parent Avocet S with resistant parent Kukuna

Table 1. Usual seedling infection type (IT) and adult plant responses (APR) observed in Mexico on race-specific genes present in CIMMYT germplasm.

Gene	Response		Line
	Seedling IT[a]	APR[b]	
Yr1	01	0	TJB368.251/Buc//Oci
Yr15	1	0	V763.2312/V879.C8.11.11.11(36)/Star/3/Star
Yr17	23	5MR	Milan
?[c]	34	5R-MR	Pastor, Bobwhite, Tinamu, Ducula
?	23	0	Catbird
?	45	5R-MR	SW89.2089/Kauz
?	45	20MR	Weaver
?	56	60M	Star
Yr28	45	30MR	Altar 84/*Ae. tauschii*//Opata
?	12	1MR	Opata//Sora/*Ae. tauschii* (323)
?	13	1MR	Croc1/*Ae. tauschii* (205)//Kauz/3/Sasia

[a] Seedling infection type follow a 0-9 scale as described in Roelfs *et al.* (1992).
[b] The APR has two components, % rust severity based on the modified Cobb Scale (Peterson *et al.* 1948) and response to infection as described by Roelfs *et al.* (1992).
[c] Unknown, probably new, genes for resistance.

Table 2. Yellow rust responses, as observed at hot-spot field sites in four countries, for resistant lines included in the genetic analysis.

Cross & selection history	New name	Yellow rust response[a]			
		Mexico	Ecuador	Kenya	Iran
Toni/Yaco//Kauz*3/Trap CG84-099Y-099M-1Y-5M-3Y-0B	Chapio	0	1	1	5R
Trap/Yaco//Kauz*3/Trap CG96-099Y-099M-17Y-6M-2Y-0B	Tukuru	1	1	1	0
Sni/HD2281//Star CG13-099Y-099M-9Y-1M-4Y-0B	Mirtu	1	1	1	20R
Sni/Toni//Kauz*3/Trap CG22-099Y-099M-50Y-2M-2Y-0B	Kuruku	1	5	1	20MR
Sni/PBW65//Kauz*3/Trap CG36-099Y-099M-69Y-1M-4Y-0B	Kukuna	1	1	1	20MR
HD2281/Pvn//Kauz*3/Trap CG40-099Y-099M-21Y-4M-5Y-0B	Konkitu	1	5	5	10MR
Pvn/Yaco//Kauz*3/Trap CG68-099Y-099M-15Y-1M-2Y-0B	Kakatsi	1	1	0	0
Pvn/PBW65//Kauz*3/Trap CG74-099Y-099M-41Y-4M-4Y-0B	Khuaki	1	1	5	10MR
Toni/Trap//Kauz*3/Trap CG78-099Y-099M-22Y-4M-1Y-0B	Tsapki	1	1	5	20MR
Toni/Yaco//Bav92 CG82-099Y-099M-5Y-4M-2Y-0B	Chos	0	1	1	1R
Trap/Yaco//Bav92 CG94-099Y-099M-10Y-1M-4Y-0B	Jarumba	0	1	1	1R

[a] Adult plant field response has two components: % severity based on the modified Cobb Scale (Peterson *et al.* 1948) and reaction to infection as described by Roelfs *et al.* (1992). Data recorded when susceptible checks show 100% severity.

Table 3. Expected frequency of lines in four phenotypic classes in the F_3 generation in the susceptible X resistant cross when resistance is controlled by genes that have minor/ intermediate but additive effects on disease severity.

No. of genes	Lines (%)			
	HPTR[1]	HPTS[2]	SegI[3]	SegS[4]
2	6.3	6.3	37.5	50.0
3	1.6	1.6	56.3	40.6
4	0.4	0.4	68.0	31.3
5	0.1	0.1	76.2	23.6

[1] HPTR = Homozygous Parental Type Resistant.
[2] HPTS = Homozygous Parental Type Susceptible.
[3] SegI = Segregating, or intermediate, but no completely susceptible plant.
[4] SegS = Segregating with completely susceptible plants.

Table 4. Distribution of F_3 lines from the crosses of yellow rust susceptible parent Avocet S with the 10 resistant wheats when evaluated at Toluca, Mexico during 2000.

Crossed with Avocet S	F_3 lines (no.)				Estimated genes (no.)	χ^2 value
	HPTR[1]	HPTS[2]	SegI[3]	SegS[4]		
Chapio	1	1	237	59	5	5.75 ns[5]
Tukuru	0	0	227	71	5	0.57 ns
Mirtu	1	0	204	93	4	1.20 ns
Kuruku	1	2	179	116	4	6.36 ns
Kukuna	0	2	192	104	4	3.58 ns
Konkitu	0	0	186	112	4	7.51 ns
Kakatsi	2	1	197	98	4	1.03 ns
Khuaki	2	1	189	106	4	3.45 ns
Tsapki	0	1	203	94	4	1.20 ns
Chos	2	2	190	104	4	3.25 ns
Jarumba	0	0	200	98	4	2.62 ns

[1] HPTR = Homozygous Parental Type Resistant.
[2] HPTS = Homozygous Parental Type Susceptible.
[3] SegI = Segregating, or intermediate, but no completely susceptible plant.
[4] SegS = Segregating with completely susceptible plants.
[5] Non-significant values at P = 0.05.

PERFORMANCE OF FOUR NEW LEAF RUST RESISTANCE GENES TRANSFERRED TO COMMON WHEAT FROM *TRITICUM TAUSCHII* AND *T. MONOCOCCUM*

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ABSTRACT

The diploid progenitors of hexaploid common wheat (*Triticum aestivum* L. AABBDD), *tauschii* (DD) and *T. monococcum* (AA), are valuable sources of genes for resistance to the leaf rust fungus *(Puccinia recondita* f.sp. *tritici).* In this study, four new leaf rust resistance genes previously transferred from these species to common wheat were considered. The gene *Lr43*, occurring in the wheat line KS92WGRC16, was transferred from *A. tauschii.* One gene, occurring in the wheat line KS92WGRC23, was transferred from *T. monococcum* var. *monococcum.* Two other genes, occurring in the wheat lines KS93U3 and KS93UI80, were obtained from *T. monococcum* var. *boeoticum.* The genes in KS92WGRC23 and KS92WGRC16 were resistant in both Kansas and Texas field tests. The gene in KS93U3 was moderately resistant in Kansas but moderately resistant to moderately susceptible in Texas. The gene in KS93UI80 was moderately resistant in Kansas but moderately resistant to susceptible in Texas. Adult plant tests conducted in the greenhouse using isolate CBBQ indicated that KS92WGRC23, KS92WGRC16, and KS93UI80 were highly resistant but KS93U3 gave a moderately resistant reaction. Typical seedling infection types produced by these lines were zero (0), fleck (;), fleck associated with chlorosis (;C), and heterogeneous (X-). Results of growth chamber studies at different temperatures (12, 16, 20 and 24°C) showed slight temperature effects on the expression of KS93UI80, only. The genes in the four lines should be used in combination with other resistance genes to prolong their usefulness.

INTRODUCTION

Genetic resistance is potentially the most cost effective and environmentally sound method of controlling leaf rust of wheat *(Triticum aestivum* L.). Unfortunately, development and management of durably resistant cultivars in the central Great Plains of the USA has not been entirely successful (1, 6). New resistant cultivars are frequently overcome by new or previously undetected races of the leaf rust fungus *(Puccinia recondita* Rob. ex. Desm. f. sp. *tritici)* after several years of large scale production. For example, the Hard Red Winter Wheat cultivars Abilene, Karl, and Newton were classified as resistant when originally released, but eventually succumbed to prevalent races. Evolution of new pathogen races in the Great Plains is favored by many factors including: (1) Large populations of inoculum produced on highly susceptible, widely grown cultivars like Chisholm and TAM 107; (2) Frequent overwintering of the pathogen on juvenile winter wheat; (3) Oversummering on volunteer wheat; (4) Deployment of many cultivars along a north-south axis which corresponds to the migration

route of the rust; (5) Reliance on a relatively small pool of resistance genes in popular cultivars; and (6) Use of only one or a few effective resistance genes in each cultivar. Development of new sources of resistance genes could ameliorate the last two problems and possibly slow the evolution of new pathogen races.

Wild relatives of cultivated wheat are a valuable source of new resistance genes for improving wheat cultivars (3, 4). The Wheat Genetics Resource Center (WGRC) at Kansas State University recently released wheat germplasm KS92WGRC16, which contains a leaf rust resistance gene (designated *Lr43)* from *A. tauschii (Coss.)* Schmal. This species is the D-genome progenitor of common wheat and is widely distributed in countries around the Caspian Sea including Turkey, Iran, Pakistan, Afghanistan, Azerbaijan, Armenia, southern Russia (Dagestan), Georgia, and Turkmenistan (5). Kihara and coworkers collected a large number of accessions of this species in 1965. Since then, this species has been well-studied (5). Three other new leaf rust genes in the wheat lines KS92WGRC23, KS93U3, and KS93UI80 were transferred from cultivated einkorn wheat (*T. monococcum* var. *monococcum*) and its wild progenitor (*T. monococcum* var. *boeoticum*). *T monococcum* is the A-genome progenitor of common wheat. It is believed that einkorn wheat was first domesticated by Neolithic farmers from *var. boeoticum.* This diploid wheat is still cultivated in mountainous areas of southern Europe and Turkey (5).

Study of the characteristics and performance of the four new leaf rust resistance genes may help optimize their use in breeding programs. For instance, determination of the typical infection types (ITs) may facilitate recognition of the resistance genes in segregating populations. This information will supplement infection type data recently compiled by McIntosh *et al.* (7). Leaf rust ITs are often affected by temperature (2). According to Clifford and Schafer (5), reducing incubation temperature provided the environment for the expression of adult plant resistance to crown rust (*P. coronata*) in oat seedlings. Pretorius *et al.* (8) detected adult plant wheat leaf rust resistance gene *Lr13* in seedlings of wheat at 25.5°C but not at 18°C. Browder and Eversmeyer (2) reported that testing at low temperature may provide an efficient means of selecting slow-rusting wheat lines. Information on temperature sensitivity will be useful in both the screening and deployment of leaf rust resistance genes.

One of the major problems in the evaluation of resistance genes is the question of whether an observed resistance is stable over areas and against diverse pathogen races in different places. Contradictory results can be obtained if one pathogen race is present some years in some areas and absent in other years or areas. Plants may remain free of disease not because they are resistant but because they escape disease. One way of addressing this problem is evaluating the test materials in several locations over several years. This approach has been followed in different plant pathogen combinations. Seedling tests to an array of leaf rust fungal isolates collected from different ecological zones will also help to check whether there is pre-existing virulence to these genes.

This study was undertaken with the following objectives: (1) to characterize the typical low infection type and other unique characteristics associated with these genes; (2) to test how well the genes perform under field conditions in Kansas and Texas, USA; and (3) to detemine if any of these genes are temperature sensitive.

MATERIALS AND METHODS

Field Studies

Winter wheat accessions containing the new leaf rust resistance genes investigated in this study are listed in Table 1. Several wheat varieties and germplasm releases, including Wrangler (PI477288), TAM 107 (PI495594), Karl 92 (PI564245), TAM 200 (PI578255), Wichita (CII952), Century (PI502912), KS91WGRC12-1, KS86WGRC2 (PI504517), KS90WGRCIO (PI549278), KS91WGRCII (PI566668), and S92WGRC15 (PI566669), were included as controls. Field nurseries were established at the Ashland experimental field, Manhattan, Kansas during the growing seasons of 1992/93, 1993/94, and 1994/95. The wheat accessions were planted in three-row plots with 20 cm between rows. Plots were 2.7 m long by 0.6-m wide with no border between plots. Experiments were arranged in a randomized complete block design with four replications.

To enhance buildup of rust epidemics, test entries were inoculated uniformly when they were between boot and early heading stages (45-53 on Zadoks' scale) of development with a mixture of urediniospores of different leaf rust fungal isolates collected from the Ashland field in previous years. Three cultures of *Puccinia recondite* Rob. ex Desm. fsp. *tritici*, CBBQ, CDBL, and MFBL were included in the rust population used to inoculate the test entries. The avirulence/virulence formulae of these rust isolates are:

CBBQ = 1, 2a, 2c, 3ka, 9, 11,16, 17, 24, 26, 30/3a, 10, 18;
CDBL = 1, 2a, 2c, 3ka, 9, 11, 16, 17, 18, 26, 30/3a, 10, 24; and
MFBL = 2a, 2c, 3ka, 9, 11, 16, 17, 18, 30/1,.3a, 10, 24, 26.

These three isolates elicit a high infection type on the hexaploid parental lines involved in producing the resistant germplasm. Urediniospores were suspended in light-weight mineral oil (Phillips Petroleum Company, Bartlesville, OK) and sprayed with a battery operated, fine nozzle sprayer between 6:00 and 7:00 p.m. after dew formation to maintain conditions necessary for spore germination and infection.

Disease severity (percentage of leaf area infected by rust in each line was assessed in Kansas twice a week between the early milk (73 on Zadoks' scale) (I0) and hard dough stages (87 on Zadoks' scale) of development using the modified Cobb scale (9). The host response to infection was scored using "R" to indicate resistance or miniature uredinia; "MR" to show moderate resistance that is expressed as small uredinia; "MS" to indicate moderately susceptible, expressed as moderate-sized uredinia (smaller than the fully compatible type); and "S" to indicate full susceptibility (9).

In Texas nurseries, single row entries of 3 m each were planted at the Texas Agricultural Experiment Stations at Prosper and Beeville in 1994/95. These nurseries were exposed to natural infection. Rust severity estimations were made at watery ripe to milky developmental stages (71-77 on Zadoks' scale).

Growth Chamber Studies

Seedlings of the four accessions with new leaf rust resistance genes along with parental lines and susceptible checks were tested twice in 12, 16, 20, and 24°C environments. The leaf rust

cultures mentioned above were used. Seeds were planted in 6- to 7-cm-diameter plastic pots filled with vermiculite. Each pot represented an experimental unit, and treatments were replicated three times in a completely randomized design. Seedlings that were 10 to 12 days old were inoculated with urediniospores (9). Briefly, urediniospores of the cultures CBBQ, CDBL, and MFBL were brought out from storage in liquid nitrogen, then were heat shocked at 40°C for 5 minutes. Primary leaves of 5 4-72 seedlings of each line were inoculated just before emergence of the second leaf using a suspension of urediniospores in light-weight mineral oil. After inoculation, the plants were misted with tap water and placed in a refrigerated (I6°C) moist chamber (I00% RH) overnight. After 16 hours of incubation, plants were allowed to dry slowly and then moved to 12, 16, 20, and 24°C growth chambers. These chambers were illuminated at about 200 μmole m^{-2} s^{-1} for 12 hours each day with light from cool white fluorescent tubes suspended about 1 m above the plants. Infection types were evaluated when they appeared to be fully developed for each temperature and were classified using the Stakman scale of 0-4 (9).

Greenhouse Studies

For adult-plant evaluations in the greenhouse, five to six seeds were sown in 6- to 7-cm diameter plastic pots filled with vermiculite. The seedlings were then vernalized at 10°C for seven weeks. At the end of vernalization, two seedlings per pot were transplanted into 15-cm-diameter plastic pots filled with a 1: 1:3 peat moss:perlite:soil mixture. Seedlings were grown at 21± 3°C with a 12-hour photoperiod in the greenhouse. Each pot represented an experimental unit, and treatments were replicated three times in a completely randomized design.

Plants were inoculated when they were at the flowering to watery ripe stages of development. After inoculation, plants were incubated in the dark in an enclosed plastic chamber with I00% relative humidity for 15 hours. They were then returned to a greenhouse with conditions similar to those described above. Disease severity was assessed on flag leaves of five randomly selected tillers 15 to 20 days after inoculation using the scales and scoring procedures described for seedling tests. This experiment was also repeated.

RESULTS

Adult Plant Reactions to Leaf Rust

Field trial results are given in Table 2. The level of leaf rust infection in the field varied among years. Infection was relatively high in the Kansas field nursery in 1992/93 but low in 1993/94 and 1994/95 seasons. The 1992/93 crop year was particularly favorable for over-wintering of the leaf rust fungus in Kansas, resulting in more than average severity on susceptible varieties (1). Rust severity also was high in Texas in 1995. The genes in KS92WGRC23 and KS92WGRC16 conferred immunity to leaf rust in both Kansas and Texas. The gene in KS93U3 was moderately resistant in Kansas but moderately resistant to moderately susceptible in Texas. The gene in KS93UI80 was moderately resistant in Kansas but moderately resistant to susceptible in Texas. TAM 200 (the hexaploid parent of KS92WGRC16), Karl 92 (the recurrent parent of KS92WGRC23), and Wrangler (the recurrent parent of KS93UI80 and KS93U3) all had high infection types under field conditions in the test areas.

Adult-plant tests conducted in the greenhouse using the isolate PBJL also showed levels of resistance similar to those observed under field conditions (Table 2). The wheat lines KS92WGRC16, KS92WGRC23, and KS93UI80 showed fleck (;), zero (0), and fleck associated with chlorosis (C), respectively. The wheat line KS93U3 was moderately resistant (20MR) producing a typical heterogeneous (X-) infection type.

Effects of Temperature on Seedling Reactions

The reactions of the four wheat lines (plus checks) to pathotypes CBBQ, CDBL, and MFBL in four environments are given in Table 3. KS92WGRC23 and KS92WGRC16 produced infection types zero (0) and fleck (;) at all temperatures with the three isolates. KS93UI80 produced a fleck infection type associated with chlorosis (C) with all three isolates in the 12 and 16°C environments. At 20 and 24°C, however, a slightly higher infection type (1C) was obtained, indicating a slight temperature effect on this line. KS93U3 showed the typical heterogeneous (X-) infection type with all three isolates at 12, 16, 20, and 24°C. Wrangler and Karl are the recurrent parents of the wheat lines carrying the resistance genes. Wrangler showed high infection types (3 to 3+) in all environments with all isolates. However, Karl gave low infection types with CBBQ and high infection types with the other two isolates in all environments. TAM 200 gave a low infection type (0 to ;1) at all temperatures. Wichita and TAM 107, the susceptible checks, produced a high infection type at all temperatures with all the three isolates (Table 3).

DISCUSSION

New rust resistance genes in the lines KS93UI80 and KS93U3 from *T. monococcum* var. *boeoticum* both provided good levels of resistance in Kansas and north Texas field tests. However, KS93UI80 and KS93U3 were moderately susceptible to susceptible in south Texas at Beeville in 1995. Texas is generally considered a "hot spot" for leaf rust (6). Therefore, the difference in performance of resistant lines between locations is likely due to greater diversity of rust pathogen races in south Texas. *P. recondita* isolates from south Texas can have different virulence combinations than isolates found in other parts of Texas (6).

Although the genes in these two lines both are derived from *T. monococcum var. boeoticum* and both appear to have the same race specificity, they are not identical. The low IT for the gene in KS93Ul80 is typically a fleck with extra chlorosis (C). In contrast, the low infection type for KS93U3 is typically heterogeneous (X-) with a mixture of pustule types. The gene in KS93UI80 also showed slight temperature sensitivity whereas the gene in KS93U3 did not. These two genes segregated independently of each other indicating that they are not allelic (T. S. Cox, unpublished).

The resistance gene transferred from *T. monococcum* var. *monococcum* to line KS92WGRC23 conferred very high resistance in all field tests. Greenhouse tests using standard races also showed very low infection types ranging from immune (0) to a few flecks (0) (Table 3).

KS92WGRC16, containing *Lr43* from *A. tauschii,* is the only line of the four that was resistant in all field and greenhouse tests. Temperature did not appear to affect the reaction, and the gene was equally effective in seedlings and adult plants. The IT of *Lr43* was very low, ranging from fleck (;) to flecks with a few small pustules associated with chlorosis (1C).

Lr43 could be a very useful new gene for development of rust resistant wheat varieties. It is highly effective, stable up to now, and no pre-existing virulence has yet been detected. On the other hand, the resistance genes in lines KS92WGRC23, KS93Ul80 and KS93U3 may be useful in some areas.

The utility of these genes would be greatly increased if they were used in combinations rather than singly. For example, a combination of KS92WGRC23 plus either KS93UI80 or KS93U3 should be resistant to many races whereas separately these lines are defeated by these races. Use of *Lr43* would also be optimized by combination with other Lr genes. Even though preexisting virulence has not yet been detected for *Lr43,* the pathogen only needs to mutate at one locus to become virulent. The leaf rust fungus has repeatedly demonstrated this capacity. However, if *Lr43* were combined with several other effective resistance genes such as *Lr2l, Lr39, Lr41, Lr42* or the genes in KS92WGRC23 and KS93Ul80, more durable resistance could result. Durability would be enhanced if the genes were not deployed singly in any cultivars. This might prevent the rust from defeating the genes in a stepwise manner.

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Questions and Answers:

Ravi Singh (Comment): The four resistance genes have been transferred to two CIMMYT spring wheat backgrounds and will be distributed in the 2001 Int. Bread Wheat Screening Nursery (IBWSN).

Answer: This is good news! Thank you.

Table 1. Pedigrees of four leaf rust resistant wheat lines.

Resistant hexaploid line	Pedigree	Resistance gene source
KS92WGRC16	Triumph 64/3/KS8010-71/ TA2470//TAM 200	*TA2470 (Triticum tauschii)*
KS92WGRC23	Karl*3//PI266844/PI355520	*PI266844 (T. monococcum* var. *monococcum)*
KS93U180	Wrangler *2/TA 749	*TA749 (T. monococcum* var. *boeoticum)*
KS93U3	Wrangler//Mustang *2/TA213	*TA213 (T. monococcum* var. *boeoticum)*

Table 2. Field and adult plant infection responses displayed by four wheat lines containing new leaf rust resistance genes and eleven controls.

	Field infection response and disease severity [a]					
	Kansas			Texas		Greenhouse
Variety or line	Manhattan			Prosper	Beeville	Adult IT[b]
	1992/93	1993/94	1994/95	1994/95	1994/95	
KS91WGRC16	0	0	0	0	0	;
KS92WGRC23	0	0	0	0	0	0
KS93U180	10MR	0	1MR	10MR	40-50S	;C
KS93U3	20MR	2MR	2MR	5-10MR	10-20MS	X-
Wrangler	30S	55S	28S	80S	80S	3+
TAM 107	30S	18S	23S	50S	70S	3+
Karl 92	50S	25S	55S	60S	70S	2+
Wichita	60S	55S	28S	40S	80S	NT[c]
TAM 200	30S	1S	1S	80S	80S	;
WGRC12-1	10MR	5MR	0	20S	10MS-MR	NT
Century	30S	9S	9S	NT	NT	3+
WGRC2	5MR	1MR	1MR	NT	NT	NT
WGRC10	5MR	8MR	0	1R	0	NT
WGRC11	0	0	0	1R	0	NT
WGRC15	5MR	0	0	0	0	NT

[a] Field infection responses are based on modified Cobb scale (9) and include two components: terminal disease severity and infection type; e.g., 1 = 1% severity, 5 = 5% severity, etc; and
0 = immune; R = resistant; MR = moderately resistant; MS = moderately susceptible; and S = susceptible infection type (IT).
[b] The greenhouse adult ITs are scored on the 0 to 4 scoring scale (9).
[c] NT = not tested.

Table 3. Seedling infection types (ITs) displayed by four wheat accessions carrying new leaf rust resistance genes and five controls when inoculated with three isolates (CBBQ, CDBL, and MFBL) of *Puccinia recondita* f.sp. *tritici* at four temperature regimes.

	12°C			16°C			20°C			24°C		
Cultivar or line	**CBBQ**	**CDBL**	**MFBL**	**CBBQ**	**CDBL**	**MFBL**	**CBBQ**	**CDBL**	**MFBL**	**CBBQ**	**CDBL**	**MFBL**
KS92WGRC16	;	;	;	;	;	;	;	;	;	;	;	;
KS92WGRC23	0	0	0	0	0	0	0	0	0	0	0	0
KS93U180	;C	;C	;C	;C	;C	;C	;1C	;1C	;1C	;1C	;1C	;1C
KS93U3	X-	X-	X-	X-	X-	X-	X-	X-	X-	X-	X-	X-
Karl 92	2-	3	3	2	3+	3+	2	3+	3+	2	3+	3+
TAM 107	3	3	3	3	3	3	3	3	3	3	3	3+
TAM 200	0;	0;	0;	0;	0;	0;	0;	0	;1	0	0	;1
Wichita	3+	3+	3+	4	4	4	4	4	4	4	4	4
Wrangler	3	3	3	3	3	3+	3	3	3+	3	3	3+

*The seedling infection types reported are (0) = no uredinia or other macroscopic sign of infection ; (;) = no uredinia, but small chlorotic flecks present; (1) = small uredinia surrounded by necrosis; (2) = small to medium sized uredinia with green islands and surrounded by necrosis or chlorosis; (3) = medium sized uredinia with or without chlorosis; (4) = large uredinia without chlorosis; (X) = heterogeneous, similarly distributed over the leaves; (C) = more chlorosis than normal for the infection type; (+) = uredinia somewhat larger than normal for the IT; and (-) = uredinia somewhat smaller than normal for the IT.

HOST RANGE OF WHEAT STEM RUST IN ETHIOPIA

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ABSTRACT

Surveys were conducted to identify the host ranges of stem rust of wheat on non-Triticum grasses collected in Arsi, Bale, East and Western Shewa, Ethiopia, during the main and off-seasons, 1997-1998. Seedlings of susceptible wheat varieties were inoculated with urediospores collected from weeds, and vice versa. Of 10 rust infected weed species, *Lolium temulentum* and *Setaria pumila* were identified to be secondary hosts for wheat stem rust. Leaves of *Avena fatua, Snowdenia polystachya, Cynodon dactylon, Bromus pectinatus* and *Euphorbia shiperiana* turned yellow, but no sporulation occurred. Wheat sown in the off-season sown and volunteer wheat in fallow lands, along the edges of crop fields, roads, irrigation canals and under orchards were found to be good sources of stem rust infection.

INTRODUCTION

Wheat is one of the most important cereal crops in Ethiopia. The area under production in Ethiopia is about 750,000 ha (Hailu, 1991). Average national wheat yields are low, ranging from 1.1 t ha^{-1} on the peasant farms to 2.0 t ha^{-1} on state farms (Hailu *et al.*, 1991).

Diseases are a major constraint to wheat production in the country. The importance of rust diseases, was recognized in 1930 by Castellani, 1938; Sibilia, 1938. Wheat stem rust is the widely distributed and can cause serious yield loss. Severity of stem rust epidemic is determined by the virulence of the pathogen, resistance of the host, favorable environment, and time available for disease development.

In some parts of the world, wild grasses or weeds play an important role in the epidemiology of wheat rust (*Puccinia* spp). A number of grass species have been observed to be susceptible to these pathogens (Roelfs *et al.*, 1992). Endemicity of rust is possible only if there is either annual continuity of hosts a resting period for the pathogen, or both. Continuity of hosts can be provided by crop cultivars, alternate host(s) or accessory graminaceous hosts (Zadoks, 1980). For instance in Mediterranean countries, uredoinoculum has a graminicolous facies, with inoculum accumulation occurring on wheat migrating to grasses situated in the Atlas mountains (Zadoks, 1965) as crop harvest occurs.

In Ethiopia, attempts have been made to investigate the specialization of stem rust on wild grasses. As a result it has been reported that *Lolium* spp. were considered as possible secondary hosts of stem rust (SPL, 1978; Loban *et al.*, 1988). However, there remains a scarcity of information available on the host range of this pathogen in Ethiopia. This paper

presents efforts made to clarify the host range of wheat stem rust in Ethiopia.

MATERIALS AND METHODS

Surveys were conducted in the major wheat growing areas of Arsi, Bale and Shewa regions in 1997 and 1998. Fields were assessed and grass weeds were observed for rust infection. Rust infected specimens were also sent to the principal author by cooperators from other research centers and development organizations.

Collected grass species seeds were sown in 10 cm diameter clay pots. Fifteen to twenty seedlings of wheat or each weed species were inoculated with urediospores from the wheat or weed species, at the two leaf stage. Spores with 100% germination rate, multiplied in greenhouse, were used for inoculation. Plants were inoculated in the evening and kept in a moisture chamber for 12-14h at 18^0C, after which they were moved to a greenhouse at 18-28 ^{0}C. Seedling of the susceptible wheat variety Morocco was inoculated with stem rust spores collected from weed species and cultivated wheat. Disease scoring was done using 0-4 scoring scale (Roelfs *et al.*, 1992). Symptoms were inspected and notes were taken 14 to 16 days after inoculation.

RESULTS AND DISCUSSION

Ten grass weed species, naturally infected by rust diseases, were collected from fields during the main and off-seasons in Shewa, Arsi and Bale regions. *Lolium temulentum* was found to be commonly infected by stem rust throughout the surveyed regions (Table 1).

Different levels of infection were observed when inoculating a susceptible wheat variety with urediospores collected from weeds of *Lolium temulentum, Setaria pumila, Avena fatua, Snowdenia polystachya, Cynodon dactylon, Bromus pectinatus* and *Euphorbia shiperiana. Andropogon* spp., *Hordeum* spp., and *Agrostis* spp. did not exhibit infection or disease symptoms (Table 2).

Reverse inoculation with stem rust urediospores collected from wheat showed highest level of infection on *Lolium temulentum* and *Setaria pumila.* The remaining eight grass weed species exhibited no infection (Table 3). During the off season survey in some parts of Bale and Showa regions wheat and other stem rust host plants grown in fallow lands, along the edges of crop fields and irrigation canals were also infected by stem rust and were hence a good source of wheat stem rust inoculum.

ACKNOWLEDGMENTS

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Questions and Answers:

Colin Wellings (Comment): I am not aware that *Lolium temulentum* and *Setaria pumila* support wheat stem rust in Australia. However, it is important to appreciate the role of grass hosts in the survival and evolution of rust pathogens.

Table 1. Incidence of stem rust infection on *Lolium temulentum* in the surveyed regions of Ethiopia, 1997-1998.

Region	Location	Altitude	Incidence (%)
Arsi	Asasa	2300	22
	Dixis	2600	2
	Bekoji	2730	2
	Lole	-	2
	Serufta	2520	3
	Lemu	2660	5
	Gofer	2520	5
Bale	Sinana	2400	10
	Adaba	2700	3
	Agarfa area	2450	10
Shoa	Debre Zeit	1850	23
	Debre Brihan	2550	3
	Sheno	2700	7
	Ambo	2225	15
	Gedo	2500	10
	Adda-Berga	--	8

Table 2. Reaction of weed species to wheat stem rust.

Weed species	Reaction*
Lolium temulentum	++ (with sporulation)
Setaria pumila	++ (with sporulation)
Avena fatua	+ (with no sporulation)
Snowdenia polystachya	+ (with no sporulation)
Cynodon dactylon	+ (with no sporulation)
Bromus pectinatus	+ (with no sporulation)
Ephorbia shiperiana	+ (with no sporulation)
Andropogon spp.	0
Hordeum spp.	0
Agrostis spp.	0

* ++ = high infection, + = hyper-sensitive.

Table 3. Reaction of weed species to stem rust collected from a susceptible wheat variety Morocco.

Inoculated weeds (species)	Disease score (0-4)
Lolium temulentum	4
Setaria pumila	3
Avena fatua	1
Snowdenia polystachya	1
Cynodon dactylon	1
Bromus pectinatus	1
Euphorbia shiperiana	1
Andropogon spp.	0
Hordeum sp	0
Agrostis sp	0

STABILITY OF STEM RUST RESISTANCE IN SOME ETHIOPIAN DURUM WHEAT VARIETIES

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ABSTRACT

In the central highlands of Ethiopia, durum wheat (*Triticum durum* Desf.) and stem rust (*Puccinia graminis* f.sp. *tritici*) have co-evolved for thousands of years resulting in a wide virulence spectrum of the stem rust fungus. Races of the pathogen in the region are among the most virulent in the world, and the Debre Zeit area is known to represent the widest virulence spectrum in the country. Five durum wheat cultivars, viz., Gerardo, Cocorit-71, Foka, Boohai and DZ-04-118, were studied from 1993/94 to 1999/00 at Debre Zeit to determine the stability of their resistance to stem rust. Two statistics suitable for measuring the stability of disease resistance over time were used in this investigation: genotypic variance (S^2_i) and coefficient of variation (CV_i). Accordingly, cultivars Foka and Boohai were found to be more stable in their resistance to stem rust than the other cultivars tested. Foka and Boohai had smaller S^2_i with values of 0.146 and 0.154, respectively; and relatively lower CV_i values of 27.30 and 30.62, respectively. Gerardo was the least stable cultivar in terms of resistance to stem rust.

INTRODUCTION

Durum wheat (*Triticum durum* Desf.) is largely grown in the central highlands of Ethiopia, at an altitude ranging from 1700 to 2900 m a.s.l. (Efrem, 1983). In this region, durum wheat and stem rust (*Puccinia graminis* Pers. f.sp. *tritici*) have co-evolved for thousands of years, and this close association has resulted in a wide virulence spectrum of the stem rust fungus (Getinet *et al.*, 1990). Stem rust is one of the major durum wheat diseases in the vicinity of the Debre Zeit Research Center (Yeshi *et al.*, 1995).

Stem rust races prevalent in the central highlands of Ethiopia are among the most virulent in the world (van Ginkel *et al.*, 1989), with the widest virulence spectrum observed at Debre Zeit where virulence for 60% of the Sr-genes tested was observed (Getinet *et al.*, 1990; Mengistu and Yeshi, 1992).

Currently, the disease is mainly controlled by the use of resistant varieties developed through hybridization and/or introduction (Mengistu and Yeshi, 1992). However, resistant varieties with acceptable level of disease resistance often rapidly succumb to the disease soon after release. Ideally, when the resistance of a variety has broken down, it should be withdrawn from production. However in practice, farmers often grow these varieties for many years. This experiment was therefore conducted to monitor the persistence/stability of resistance in released durum wheat varieties to stem rust at Debre Zeit, Ethiopia.

MATERIALS AND METHODS

Five durum wheat varieties released in Ethiopia (Gerardo, Cocorit-71, Foka, Boohai, and DZ-04-118) were tested in the 1993/94 to 1999/2000 cropping seasons at Debre Zeit, Ethiopia for reaction to stem rust. Planting was conducted in four replicates (three replicates in the 1999/00 crop season) using a randomized complete block design (RCBD) on 3m x 3m plots. The local susceptible durum wheat variety, DZ-04-118, was used as a check. The disease, developed from natural infection, was assessed after heading using the modified Cobb's scale. Data were recorded for stem rust severity and reaction types and were converted into coefficient of infection (C.I.), which were transformed into logarithmic scales to stabilize variances (Petersen, 1994).

According to Becker and Leon (1988), stability can be divided into two groups: static and dynamic concepts of stability. The dynamic concept of stability deals with yield or other quantitative traits that react similarly to favorable or unfavorable environmental conditions. The static concept of stability is useful for traits, the level of which have to be maintained at all costs, e.g. for quality traits, for resistance against diseases, or for stress characters such as winter hardiness.

Lin *et al.* (1986) and Xie and Mosjids (1996) suggested genotypic variance (S^2_i) and genotypic coefficient of variation (CV_i) as appropriate measures of stability of static traits. We used two statistics to determine the stability of durum wheat varieties for resistance to stem rust, computed as follows:

$$S_i^2 = \sum_{j=1}^{q} (X_{ij} - 8_i.)^2/q-1; \text{ and}$$

$$CV_i = S_i/ 8_i. * 100;$$

where Xij = the observed mean stem rust severity value of genotype *i* in year *j*; $X_{ij} - 8_i.$ = deviation from the average stem rust severity; q = number of years; and $8_i.$ = mean of genotype *i* over all years. Years were considered as separate environments since the experiment was conducted at one location, i.e., Debre Zeit, Ethiopia. Locations, years and cultural practices usually result in similar reactions of a genotype and thus can replace one another (Becker and Leon, 1988).

RESULTS AND DISCUSSION

For stability to be considered, the variety x year interaction need to be significant; otherwise, one could directly select any variety with the lowest mean stem rust severity. The results of the combined ANOVA showed that there was a highly significant ($P = 0.01$) variety x year interaction (Table 1). Stability parameters were calculated as indicated in Table 2. According to Petersen (1994) and Becker and Leon (1988), the smaller the numerical values of S^2_i and CV_i, the more stable is the genotype.

The susceptible check cultivar, DZ-04-118, showed the highest mean stem rust severity (Table 2). Cultivars Cocorit-71 and Boohai expressed the highest degree of resistance,

however, there were no significant differences (P = 0.01) among the mean stem rust severities exhibited by Boohai, Cocorit-71 or Foka.

Foka and Boohai were stable in their resistance to stem rust (Table 2). They had lower mean stem rust scores with values of 1.42 and 1.28, and smaller S^2_i with values of 0.146 and 0.154, respectively, and relatively lower CV_i with values of 27.30 and 30.62, respectively. Boohai, released in 1982, remains resistant to stem rust, and may thus be considered to exhibit durable resistance to stem rust (DZARC, 1997).

Although Cocorit-71 exhibited a low value for mean stem rust severity (1.28), variable reaction over years resulted in its poor stability for resistance to stem rust. Low means with high CV_i and S^2_i indicate that means are not efficient measures of stability for disease resistance.

CONCLUSIONS

Evidence is presented concerning the stability of resistance to stem rust by the cultivars Foka and Boohai as tested over six years. These cultivars may exhibit durable resistance to stem rust. Studies to ascertain the number and diversity of genes for resistance should be performed to enable breeders to effectively use these cultivars for development of resistant cultivars.

There should be little danger in growing Cocorit-71 at Debre Zeit since its resistance to stem rust is reasonably stable. The variety should be grown as long as it shows a reasonable resistance to the disease.

Gerardo was the most susceptible cultivar observed relative to the susceptible check DZ-04-118. The variety was found to be unstable in its resistance to stem rust. With regular close supervision of its status of resistance, the variety Gerardo may remain under production for some years until it becomes critically susceptible to the disease.

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Questions and Answers:

Colin Wellings: You indicated that genetic analysis of the resistance in the resistant durums will be undertaken. Do you intend to combine this with a detailed study of variation in the pathogen?

Answer: Yes, there is a plan to do race identification for the stem rust fungus at regular intervals. When we'll be able to set up such studies, it will be possible to combine it with a stability study which is continuous.

Table 1. A combined ANOVA for the six test years (1993/94 to 1999/00).

Source	DF	Adjusted SS	Adjusted MS	F Ratio
Variety (V)	4	3.5353	0.8838	6.35**
Years (Y)	5	7.4477	1.4895	10.70**
V x Y	20	11.4343	0.5717	4.11**
Error	82	11.4192	0.1393	--
Total	114	--	--	--

** Significant at $P \leq 0.01$.

Table 2. Mean stem rust severity and stability statistics for stem rust resistance in durum wheat varieties tested over six years at Debre Zeit, Ethiopia.

Genotype[1]	Year of release	Mean stem rust severity (log C.I.)[2]	Stability statistics[3]	
			S^2_i	CV_i
Gerardo	1976	1.48*ab*	0.249	33.69
Cocorit-71	1976	1.28*b*	0.199	34.82
Foka	1993	**1.42*b***	**0.146**	**27.30**
Boohai	1982	**1.27*b***	**0.154**	**30.62**
DZ-04-118	1966	1.75*a*	0.202	25.71

[1] The figures in parentheses indicate the years of release of the respective cultivars.
[2] C.I.: coefficient of infection, significant at $P \leq 0.01$.
[3] S^2_i: genotypic variance; and CV*i*: genotypic coefficient of variation.

FIELD RESPONSE OF BREAD WHEAT GENOTYPES TO *SEPTORIA TRITICI* BLOTCH

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ABSTRACT

A field experiment was conducted in order to evaluate bread wheat genotypes for resistance to *Septoria tritici* blotch. Thirty-six bread wheat genotypes were evaluated at the Bekoji and Holetta Agricultural Research Centers. The combined analysis of variance showed that the mean squares due to genotypes, environments and the interaction effect were significant ($P<0.01$) for percentage necrotic leaf area. Mean separation of the percentage necrotic leaf area showed that advanced lines HAR 3640, HAR 3638, HAR 1698, HAR 2096, HAR 3641 and a commercial cultivar Mitike were resistant to *Septoria tritici* blotch as compared to a susceptible check. A significant negative correlation was found between the disease severity and days to heading and plant height. A resistance parameter, deviation from the regression of infection on days to heading and height, was defined by eliminating the linear effects of escape mechanisms by late heading or tall stature. Using this resistance parameter, the advanced lines mentioned above were found to have true genetic resistance with the exception of HAR 3640. The resistance observed under field conditions for HAR 3640 was due to escape mechanism(s). This study recommends that when screening germplasm for resistance to *Septoria tritici* blotch, the severity data must be corrected for the effects of days to heading and plant height, especially when the genotypes are not grouped into maturity classes.

INTRODUCTION

Diseases caused by fungi are among the most important biotic factors constraining wheat production. Yellow rust (*Puccinia striiformis* f.sp. *tritici*), stem rust (*Puccinia graminis* f.sp. *tritici*), and septoria diseases especially septoria tritici blotch (*Septoria tritici*) are prevalent throughout Ethiopia (Eshetu, 1985). Septoria tritici blotch (STB), caused by the fungus *Mycosphaerella graminicola* (Fuckel) Schroeter (asexual state: *Septoria tritici* Rob. ex. Desm.), is a disease of both bread and durum wheats. It is important in warm and humid wheat growing areas of the world especially in the coastal areas of the Mediterranean, South America, the highlands of East Africa, Australia and Western Europe (Rajaram and Dubin, 1977; Saari and Wilcoxson, 1974).

The occurrence of STB in Ethiopia was documented by Stewart and Dagnachew (1967), SPL (1975, 1978) and Getinet *et al.* (1990).

Yield losses due to STB in Ethiopia. 25% were observed at Debre Zeit ARC with a high level of septoria infection, especially on semi-dwarf varieties (Dagnachew, 1969). In a field

experiment conducted at Holetta ARC, 82% grain yield loss was recorded due to this disease under natural infection (IAR, 1971). Thus the seriousness of STB outbreaks have made it imperative to devise suitable control measures.

Resistance in wheat to *Septoria tritici* has been demonstrated by a number of researchers, and breeding for resistance is likely to be the most practical method of control (Arama, 1996). Several sources of resistance have been reported but breeding for resistance has not always been successful in protecting wheat cultivars from the damaging effects of the disease (Mann *et al.*, 1985; Rajaram and Dubin, 1982), because expression of resistance is often correlated with morphological traits such as plant height, maturity and canopy architecture (Eyal *et al.*, 1985). Moreover, wheat cultivars resistant in one part of the world may display susceptibility elsewhere. Even within countries, differences observed in virulence may be associated with fungal genetic variability (Eyal *et al.*, 1973; 1985). Thus, the objective of this experiment was to evaluate the response of bread wheat genotypes against the prevailing *Septoria tritici* population at two locations in Ethiopia.

MATERIALS AND METHODS

Plant Materials, Experimental Design and Procedures

The field experiment was conducted at two locations; Bekoji and Holetta ARC, Ethiopia, both hot spot areas for STB. Thirty-six bread wheat genotypes, including a standard check (Kubsa) and a susceptible check (Laketch), were used in the experiment (Table 1). The experiment was conducted using a plot size of 1.6 m^2 (4 rows of 2 m long and 20 cm between rows) in a simple lattice design with two replications. The genotypes were evaluated under natural disease epidemics during the 1998 main cropping season, June to November. All standard cultural practices were applied as recommended for each location. Disease assessments were made when the genotypes were on average between medium milk and late milk growth stages using the double digit 00-99 scoring scale (Saari and Prescott, 1975; Eyal *et al.*, 1987). At the same growth stage, the percentage necrotic leaf area on the flag leaf (F) and penultimate leaf (F-1) was estimated. For estimating the percentage necrotic leaf area, ten tillers were sampled at random from the two central rows of each plot. The percentage of necrotic leaf area was combined for the two leaves on each tiller and averaged for the ten tillers observed in each plot.

Statistical Procedures

Analysis of variance

Analysis of variance for simple lattice design was performed for percentage necrotic leaf area and grain yield separately for the two locations using MSTATC computer software statistical package (Michigan State University, 1989). Since the simple lattice design used in this study was more efficient than a Randomized Complete Block Design for the two response variables, the treatment means were adjusted accordingly. In order to determine the performance of the bread wheat genotypes across locations, a combined analysis of variance for the two variables was performed.

Regression analysis

In order to identify the true genetic resistance of bread wheat genotypes to STB a multiple linear regression analysis was done in order to correct the linear effects of days to heading (DH) and plant height (HT) on percentage necrotic leaf area following the procedures of van Beuningen and Kohli (1990).

Similar to the percentage necrotic leaf area, the linear effects of days to heading and plant height on severity of STB assessed using the double-digit 00-99 scoring scale was analyzed. Following the procedures of van Beuningen and Kohli (1990) a coefficient of infection (CI) was derived by multiplying the two digits of the double digit 00-99 scale. To calculate a balanced average, these original disease scores were converted to relative values, expressed as a percentage of the maximum reading at the same testing location and referred to as the relative coefficient of infection (RCI).

The relative coefficient of infection obtained was then utilized in computing the multiple linear regression to investigate the relationship between disease severity due to STB, and days to heading and plant height.

From the multiple linear regression analysis the observed RCI (Y) was expressed as a linear function of days to heading (DH) and plant height (HT), giving the following regression model.

$$Y = \alpha + (\beta_1 \times DH) + (\beta_2 \times HT) + e$$

Where: α = intercept
β_1 and β_2 = partial regression coefficients
DH = days to heading
HT = plant height
E = error term

Using this model, the expected RCI, the value for which the effects of days to heading and plant height are removed, was calculated. The difference between the observed RCI and expected RCI constitutes an improved approximation of the true genetic resistance which is expressed as the error term "e", or those components of resistance that do not depend on days to heading and plant height, although it also includes nonlinear effects of DH and HT and environmental error. When "e" is expressed in units of the standard error of regression, the value obtained is referred to as the deviation from the regression of infection on DH and HT (DRIHH). This allowed an immediate interpretation of the resistance.

RESULTS AND DISCUSSION

Reactions of Bread Wheat Genotypes to STB

The analysis of variance for the individual locations and the combined analysis of variance for the mean percentage necrotic leaf area is presented in Table 2. The combined analysis of variance indicated that the main effects of genotypes and environment were significant (P=0.01). The genotype and environment interaction was also significant (P=0.01). The significance of the mean square due to G x E indicates that genotypes differ from one

location to another in terms of their reaction to STB. On the other hand the significance of G x E indicates possible differences in pathogen virulence spectrum between the two locations.

The magnitude of the G x E interaction was low as compared to the main effects of genotypes. This indicates that some genotypes performed consistently across locations. Hence those genotypes which performed better across the two locations were selected through mean separation. Comparison of the mean percentage necrotic leaf area (Table 3) indicated that HAR 3640 was significantly different (P=0.05) from the susceptible check, Laketch followed by the advanced lines such as HAR 3638, HAR 1698, HAR 2096, HAR 3641, and the cultivar Mitike.

Interestingly, recently released cultivars such as Magal and Wabe were more susceptible to STB than Laketch. This may be explained by yellow rust infection that occurred late in the season at Bekoji on Laketch competing for the remaining green leaf area of flag and penultimate leaves, and hence, the development of STB on Laketch could not progress further.

The percentage necrotic leaf area on HAR 3634 (=Bob white), was low indicating an effectiveness of the resistance genes in this genotype. However, virulence on HAR 3634 has already been reported in other countries such as Argentina (Cordo *et al.*, 1994) and in Mexico (Gilchrist and Velazquez, 1994).

Effect of Days to Heading and Plant Height on Severity of STB

STB assessed using percentage necrotic leaf area

The effect of days to heading (DH) and plant height (HT) on percentage necrotic leaf area was assessed by multiple linear regression analysis. The regression and partial regression coefficients for this analysis are presented in Table 4.

The analysis of variance due to regression of percentage necrotic leaf area on days to heading and plant height, presented in Table 5, indicated that both agronomic characters significantly (P=0.01) affected percentage necrotic leaf area. However, days to heading and plant height accounted for only about 29% of the variation in observed percentage necrotic leaf area.

From the multiple linear regression analysis, the following regression model was developed in order to modify the observed percentage necrotic leaf area.

$$\text{Percentage necrotic leaf area} = 258.243 - 1.693DH - 1.036HT + e$$

The observed, expected percentage necrotic leaf area and the deviation from the regression of the infection on DH and HT (DRIHH) of bread wheat genotypes with superior resistance are presented in Table 6. A value of -1.5 for a genotype implies that it would be situated 1.5 units from the standard error below the regression plane and indicates that the genotype would have considerably less infection than can be explained by the linear effects of heading date or plant height.

After correcting the observed percentage necrotic leaf area, advanced lines found to be resistant to STB through analysis of variance are still resistant to STB. However, HAR 3640 which was reported to be the most resistant through analysis of variance of observed

percentage necrotic leaf area, was not selected as resistant after correcting percentage necrotic leaf area. This result indicated that when genotypes are evaluated under natural conditions, taller or late maturing varieties tend to escape disease infection and may wrongly be considered resistant.

STB assessed using the double digit 00-99 scale

In order to identify the true genetic resistance using this scoring method, the relationship between (RCI), and days to heading (DH) and plant height (HT) was analyzed using the multiple linear regression (Table 7). The RCI, DH and HT appeared to vary among genotypes but there was an association among these variables.

The analysis of variance for the multiple linear regression is presented in Table 8. The results indicated that days to heading and plant height significantly affected relative coefficient of infection due to STB. However, days to heading and plant height accounted for only about 28 % of the variation in relative coefficient of infection. This low correlation coefficient may be due to lack of variability for heading or height among the genotypes tested. The range between minimum and maximum heading date was 21 days. The range for plant height looks high, about 50 cm, but it was because one entry, HAR 3640, is relatively tall, 130 cm, with the remaining cultivars and advanced lines, either semi-dwarf or medium tall.

From the multiple regression analysis the following regression model was developed in order to correct the relative coefficient of infection and thus identify the true genetic resistance.

$$RCI = 228.92 - 1.61DH - 0.80HT + e$$

The observed, expected RCI and the deviation from the regression of the infection on days to DH and HT (DRIHH) of bread wheat genotypes with superior resistance is presented in Table 9. A value of -1.6 for a genotype implies that it would be situated 1.6 units of the standard error below the regression plane and indicates that it has considerably less infection than can be explained by the linear effects of its heading and height.

The results of this study indicated that the severity of STB assessed using both percentage necrotic leaf area and double digit 00-99 scale are associated with days to heading and plant height. In agreement, Eyal *et al.* (1983) reported the association between resistance to STB and days to heading and plant height. Tavella (1978) concluded that plant height was negatively correlated with wheat STB disease severity. We found a low but significant correlation coefficient between percentage necrotic leaf area and days to heading and plant height. Similar correlation was found for relative coefficient of infection.

These results are in contrast to Arama (1996) who did not observe an effect of plant height on the observed disease severity. On the other hand, Eyal and Talpaz (1990) and van Beuningen and Kohli (1990) have observed significant effects of heading date and plant height on severity of STB. The present finding is in agreement with the findings of Jilbene *et al.* (1992) and Camacho-Casas *et al.* (1995) who showed the association between reduced disease severity with late maturity and tall plant height.

Grain Yield Performance of Bread Wheat Genotypes

The analysis of variance for the individual locations and the combined analysis of variance for grain yield are presented in Table 10. The combined analysis of variance for the mean grain yield indicated that highly significant difference (P=0.01) were observed among the genotypes. The main effect of the environment and the interactions were also significant. The significance of G x E interaction indicated that the yield performance of the genotypes differed between locations.

The magnitude of the interaction effect was low, as compared to the main effects of the genotypes, indicating that some genotypes performed consistently across the locations. Comparison of mean grain yield of bread wheat genotypes showed that advanced lines such as HAR 1882, HAR 1755, HAR 1698 and commercial cultivar Mitike significantly yielded better than the standard check, Kubsa (Table 11). Advanced lines HAR 3638 and HAR 2096 which were found to be resistant to STB based on corrected percentage necrotic leaf area and double digit 00-99 scale also had reasonable grain yield compared with Kubsa. The grain yield data was considered to have an insight into the yield potential of advanced lines which showed resistance to STB that may be used in transferring resistant genes to high yielding but susceptible cultivars to STB in the future improvement program.

SUMMARY AND CONCLUSIONS

A combined analysis of variance for the percentage necrotic leaf area showed that the main effects of the genotypes, environments and the interaction effect were significant (P=0.01). The advanced lines HAR 3640, HAR 3638, HAR 1698, HAR 2096, HAR 3641 and Mitike were resistant to STB as compared to Laketch.

A multiple linear regression analysis showed that the percentage necrotic leaf area was significantly affected by days to heading and plant height. The advanced lines indicated above have true genetic resistance as observed through deviation from the regression of infection from days to heading and plant height. However, the resistance observed under field conditions for HAR 3640 was mainly due to escape mechanisms involving late maturity and tall plant stature. The performance of the genotypes followed a similar trend for the double digit 00-99 score. The ranking of genotypes, however, varied between assessment methods.

This study suggested that in screening germplasm for resistance to *Septoria tritici* blotch, severity data should be corrected for the effects of days to heading and plant height, especially when the genotypes are not grouped into maturity classes.

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Table 1. List of bread wheat genotypes used in the field experiment.

Code	Variety	Cross/Pedigree
01	K6295-4A	ROMANY x GB-GAMENYA
02	ET-13A2	ENKOY UQ105 SEL.
03	ENKOY	[HEBRAND SEL/(WIS245 x SUP51]x[(FR-FN/Y)^{2} A]
04	MITIKE	BOW 28 RBC
05	DASHEN	KVZ/BUHO "S"//KAL/BB
06	WABE	MRL "S" BUC "S"
07	GALAMA	4777 (2)//FKN/GB/3/PVN "S"
08	MAGAL	F371/TRM//BUC "S"/3/LIRA "S'
09	ABOLA	BOW "S'/BUC "S"
10	TUSIE	COOK/VEE "S"//DOVE "S"/SERI
11	HAR 1706	BOW "S"/BUC "S"
12	KATAR	COOK/VEE "S"//DOVE "S"/SERI/3/BJY "S"
13	HAR 1875	GOV/AZ//MUS "S"
14	HAR 1868	GOV9/AZ//MUS "S"/3/R37 GHL121//KAL/BB/4/ANI "S'
15	TURA	ARO YR SEL.60/89
16	HAR 1852	NDVG 9144 //KAL/BB/3/YACO "S"/4/CHIL "S'
17	HAR 2096	FURY-KEN/SLM//ALDAN/4/PATO//PAT2300/3/PVN
18	HAR 1882	F6 74/BUN "S"//SIS "S"/3/THB "S"
19	HAR 2073	NDVG 9144 //KAL/BB/3/YACO "S"/4/CHIL
20	HAR 2103	NESTOR
21	HAR 1755	SUNBIRD 56 ROMANY BC
22	HAR 1698	IAS 58/4/KAL/BBCI "S"/3/ALD "S"/5/BOW "S" (=TINAMOU)
23	HAR 1861	BOW "S"/NKT "S"
24	HAR 1864	URES/BOW 'S"
25	HAR 1874	DOVE "S"/BOW "S"
26	HAR 3634	BOBWHITE
27	HAR 3635	CNO79/4/CS/TH.CU//GLEN/3/ALD/PVN
28	HAR 3636	CHIRYA.1 Do.
29	HAR 3637	CS/TH.CU//GLEN/3/ALD/PVN/4/SUZB
30	HAR 3639	ALD/PVN//YMI #6
31	HAR 3640	IAS 20
32	HAR 3641	KVZ/K4500.L.6.A.4
33	HAR3642	GLENNSON M 81
34	HAR 3638	EG-A/H567.71//4*EG-A/3/2*CMH79.243
35	KUBSA	NDVG 9144 //KAL/BB/3/YACO "S"/4/VEE "S"
36	LAKETCH	PJ "S" GB55

Table 2. Analysis of variance of percentage necrotic leaf area at Bekoji and Holetta, and combined analysis of variance across locations, 1998.

		Bekoji	Holetta
Source of variation	**df**	**Mean square**	**Mean square**
Replications	1	40.951	31.205
Genotypes			
- Unadjusted	35	1205.017*	2150.796*
- Adjusted	35	1194.764*	2141.044*
Blocks within Reps (adj.)	10	62.407	5.99
Error			
-Effective	25	31.558	30.667
-RCB Design	35	37.241	31.047
-Intrablock	25	27.175	29.069
Efficiency of lattice over RCBD (%)		18	1
Combined analysis of variance across locations			
Source of variation	**df**	**Mean square**	
Genotype	35	1326.463*	
Environment	1	354.001*	
G x E	35	341.443*	
Pooled error	50	15.556	

*Significant at P=0.01

Table 3. Mean percentage necrotic leaf area of 36 bread wheat genotypes tested at Bekoji and Holetta, 1998 for *Septoria tritici* blotch (Laketch = susceptible check).

Cultivar/Line	Bekoji	Holetta	Across location
K6295-4A	36.74	13.01	24.88
ET-13A2	22.49	29.49	25.99
ENKOY	24.13	15.85	19.99
MITIKE	11.52	16.12	13.82
DASHEN	10.58	51.31	30.95
WABE	77.29	99.95	88.62
GALAMA	69.51	36.46	52.98
MAGAL	92.95	97.94	95.45
ABOLA	69.24	86.6	77.92
TUSIE	26.78	17.22	22.00
HAR 1706	66.29	88.56	77.43
KATAR	73.05	25.85	49.45
HAR 1875	40.89	20.73	30.81
HAR 1868	91.94	12.57	52.25
TURA	37.63	8.23	22.93
HAR 1852	44.52	24.84	34.68
HAR 2096	9.83	14.94	12.38
HAR 1882	14.29	17.58	15.93
HAR 2073	72.44	99.49	85.96
HAR 2103	51.04	62.62	56.83
HAR 1755	30.98	12.78	21.88
HAR 1698	17.72	5.75	11.73
HAR 1861	48.53	40.34	44.43
HAR 1864	26.84	40.98	33.91
HAR 1874	28.43	13.89	21.16
HAR 3634	34.23	12.47	23.35
HAR 3635	18.52	28.83	23.67
HAR 3636	26.41	22.45	24.43
HAR 3637	28.47	7.94	18.20
HAR 3639	17.43	17.58	17.50
HAR 3640	9.00	2.54	5.768
HAR 3641	23.44	3.27	13.36
HAR 3642	58.34	93.28	75.81
HAR 3638	5.48	10.15	7.81
KUBSA	54.88	7.89	31.39
LAKETCH	47.84	100.0	74.16
SE (m) ±	4.0	3.9	2.8
LSD (P=0.05)	11.6	11.4	7.9
C.V.(%)	14.2	15.8	10.6

Table 4. Estimates of the regression and partial regression coefficients between percentage necrotic leaf area, and days to heading and plant height.

Variable	Regression coefficient	Standard error	Partial regression coefficient	Std. error of partial coef.
DH	-1.69	0.70	-0.35*	0.15
HT	-1.04	0.38	-0.41**	0.15

* Significant at P=0.05
** Significant at P=0.01

Intercept = 258.248
Coefficient of Determination (r^2) = 0.29
Standard Error of regression = 22.403

Table 5. Analysis of variance due to regression of percentage necrotic leaf area on days to heading and plant height.

	df	Mean square
Regression	2	3370.73*
Residual	33	501.89
Total	35	

* Significant at P=0.01

Table 6. Bread wheat genotypes with superior resistance to STB assessed using percentage necrotic leaf area.

Cultivar/Line	Days to heading	Height (cm)	STB		
			OPNLA[a]	EPNLA[b]	DRIHH[c]
HAR 1882	66.00	93.0	14.4	47.5	-1.5
HAR 3638	69.00	96.5	7.15	38.7	-1.4
HAR 3636	65.50	88.0	25.5	53.6	-1.3
ENKOY	63.75	96.5	20.6	47.5	-1.2
HAR 3641	73.25	93.5	12.0	34.7	-1.0
TUSIE	67.25	93.0	23.3	45.3	-1.0
HAR 1755	64.00	98.0	23.3	45.5	-1.0
HAR 3634	68.25	91.5	23.7	45.3	-1.0
HAR 2096	75.00	93.0	12.1	32.2	-0.9
TURA	74.00	87.0	22.9	40.3	-0.8
HAR 1698	76.75	92.0	13.2	30.3	-0.8
MITIKE	65.75	110.0	14.4	29.8	-0.7
HAR 1874	70.25	97.5	21.1	35.5	-0.6

[a] Observed percentage necrotic leaf area
[b] Expected percentage necrotic leaf area
[c] Deviation from the regression of infection on heading and height

Table 7. Estimates of the regression and partial regression coefficients between relative coefficient of infection, and days to heading and plant height.

Variable	Regression Coefficient	Standard error	Partial Reg. Coefficient	Std. Error of Partial Coef.
DH	-1.61	0.6	-0.39**	0.15
HT	-0.80	0.3	-0.36*	0.15

** Significant at P≤ 0.01
* Significant at P≤ 0.05

Intercept = 228.92
Coefficient of Determination (r^2) = 0.281
Standard Error of regression = 19.275

Table 8. Analysis of variance due to regression of relative coefficient of infection on days to heading and plant height.

	df	Mean Square
Regression	2	2399.01*
Residual	33	371.52
Total	35	

* Significant at P≤ 0.01

Table 9. Bread wheat genotypes with superior resistance to STB assessed using double digit scale.

Cultivar/Line	Days to Heading	Height (cm)	STB		
			ORCI[a]	ERCI[b]	DRIHH[c]
HAR 1755	64	98	17.36	47.48	-1.6
HAR 3638	69	97	13.59	40.63	-1.5
HAR 1882	66	93	22.74	48.26	-1.4
TUSIE	67	93	20.83	46.25	-1.3
TURA	74	87	14.93	40.18	-1.3
MITIKE	66	110	12.5	35.06	-1.2
ENKOY	64	97	29.86	49.08	-1.0
HAR 1874	70	98	20.49	30.89	-0.9
HAR 2096	75	93	17.75	33.77	-0.8
HAR 1852	72	97	20.83	34.43	-0.7
HAR 1698	77	92	18.32	31.75	-0.7
HAR 3634	68	92	32.39	45.84	-0.7
HAR 3641	73	94	21.18	32.19	-0.6
HAR 3636	66	88	43.75	53.07	-0.5
K6295-4A	69	112	24.42	29.44	-0.3
ET-13A2	73	102	26.39	29.79	-0.2
HAR 1864	80	87	28.82	30.52	-0.1

[a] Observed relative coefficient of infection.
[b] Expected relative coefficient of infection.
[c] Deviation from the regression of infection on heading and height.

Table 10. Analysis of variance of the grain yield (kg/ha) at Bekoji and Holetta, and combined analysis of variance across locations, 1998.

Source of Variation	df	Bekoji Mean square	Holetta Mean square
Replications	1	198188	72279
Genotypes			
- Unadjusted	35	5698394*	906708*
- Adjusted	35	5704401*	889656*
Blocks within Reps (adj.)	10	121233	407564
Error			
- Effective	25	80826	172190
- RCB Design	35	86423	220348
- Intrablock	25	72500	145463
Efficiency. of lattice over RCBD (%)		6.9	28
Combined analysis of variance across locations			
Source of variation	**df**	**Mean Square**	
Genotype	35	1881612*	
Environment	1	4783390*	
G x E	35	1415416*	
Pooled error	50	63254	

* Significant at P=0.01

Table 11. Mean grain yield (kg/ha) of 36 bread wheat genotypes at Bekoji, Holetta and across locations, 1998.

Cultivar/Line	Bekoji	Holetta	Across location
K6295-4A	3502	3782	3642
ET-13A2	4444	2241	3343
ENKOY	4688	2055	3371
MITIKE	5599	3326	4463
DASHEN	330	2499	1415
WABE	626	3237	1932
GALAMA	273	3189	2961
MAGAL	1899	2482	2190
ABOLA	1930	1879	1904
TUSIE	3669	3615	3642
HAR 1706	2192	3030	2611
KATAR	1795	4409	3102
HAR 1875	1057	2943	2000
HAR 1868	2480	3665	3073
TURA	2819	3049	2934
HAR 1852	845	3531	2188
HAR 2096	3111	4388	3749
HAR 1882	6191	3687	4939
HAR 2073	507	3014	1761
HAR 2103	1623	2783	2203
HAR 1755	5382	3486	4434
HAR 1698	5041	3788	4415
HAR 1861	380	2962	1671
HAR 1864	2868	3537	3203
HAR 1874	2749	3156	2952
HAR 3634	1192	3465	2329
HAR 3635	692	2985	1838
HAR 3636	102	3136	2076
HAR 3637	2691	2531	2611
HAR 3639	2325	3186	2755
HAR 3640	3580	2748	3164
HAR 3641	3547	2173	2860
HAR 3642	704	3126	1915
HAR 3638	5247	2906	4076
KUBSA	3337	4081	3709
LAKETCH	79	1357	718
SE (m) ±	210.0	293.4	177.84
LSD (P=0.05)	585.5	854.6	501.60
C.V.(%)	11.0	13.4	8.86

IS IT NECESSARY TO APPLY INSECTICIDES TO RUSSIAN WHEAT APHID RESISTANT CULTIVARS?

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ABSTRACT

Wheat cultivars resistant to Russian wheat aphid (*Diuraphis noxia*) have been available to farmers in the Free State Province of South Africa since 1992. Resistance conferred by the genes *Dn1* and *Dn2* is known to reduce the percentage of tillers infested with aphids as well as lower the number of Russian wheat aphids per infested tiller. In addition, a dramatic increase in yield is associated with this resistance when these cultivars are compared to susceptible wheat lines. Since aphids still occur on these cultivars, producers often ask whether it would be possible to increase yields further by applying insecticide to control the remaining aphids. Trials have shown that it is indeed possible to increase grain yields, using insecticides, but that these increases are not always economically justifiable: the combined cost of insecticide and its application are not always recovered. Factors such as Russian wheat aphid infestation level, and input cost relative to the grain market price are important profit determinants.

INTRODUCTION

The Russian wheat aphid (RWA) (*Diuraphis noxia* (Kurdjumov)) has had a major impact on the South African wheat industry since the early 1980's. South Africa annually produces 1.5 to 2 MT of wheat, most of which is produced in the summer rainfall region of the Free State where *D. noxia* is a serious pest of wheat. Symptoms of *D. noxia* infestation on susceptible plants are distinct white, yellow and purple to reddish-purple longitudinal streaks and severe rolling of the leaves of infested plants (Walters *et al.*, 1980). The aphids are found mainly on the adaxial surface of the newest growth, in the axils of leaves or within rolled leaves. Tillers of young plants become prostrate under heavy infestations and at later growth stages heads become trapped in the rolled flag leaf. Apart from causing substantial yield losses, RWA has also prevented the planting of late-winter, intermediate and spring wheat in this region of South Africa (Du Toit and Walters, 1984; Du Toit, 1992). *D. noxia* infestation leads to a reduction in chlorophyll content (Kruger and Hewitt, 1984) which, when combined with leaf rolling, causes a considerable loss of effective leaf area on susceptible plants (Walters *et al.*, 1980). Burd and Burton (1992) showed that RWA infestation resulted in water imbalances in the host plant, expressed as loss of turgor and reduced growth leading to substantial reductions in biomass. It is therefore not surprising that farmers view the small populations of RWA on resistant cultivars with much suspicion and often ask whether it would not be possible to increase the yields further by insecticide control of the remaining aphids. This paper discusses whether it is justified to apply insecticides to RWA resistant wheat cultivars.

MATERIALS AND METHODS

The RWA resistant winter wheat cultivar Gariep, which contains the resistance gene *Dn1*, was field tested near Bethlehem, Free State Province, South Africa, with and without insecticides, from 1994-1998 in a split-plot design with five replications. Insecticide treatments included an Imidacloprid WS seed-dressing (Gaucho®, 140 g ai per 100 kg seed); a foliar spray of a Demeton-S-Methyl EC / Parathion EC mixture (125g ai ha^{-1} + 325g ai ha^{-1}, respectively) at Zadoks GS 30; and a combination of both treatments. Yield and hectoliter mass (HLM), which determine grade and price, were used to calculate the benefit of the insecticide treatment using the cost of insecticides and wheat prices for the 1998 season. The cost of a Gaucho® seed dressing was calculated at R 114.00 ha^{-1} and that of the foliar spray at R 214.00 ha^{-1}.

RESULTS

The yield potential varied from year to year with the highest yield being obtained in the 1996 season and the lowest in 1994 (Table 1). Yield and hectoliter mass are shown as they determine the income per hectare from each particular treatment. In 1995 the low hectoliter mass resulted in downgrading of the crop and a lower price per ton. The use of a Gaucho® seed dressing on Gariep led to a decrease in yield in all five years that the trial was conducted. The application of the foliar spray of a Demeton-S-Methyl EC/Parathion EC mixture (125g ai ha^{-1} + 325g ai ha^{-1}, respectively) at Zadoks GS 30 lead to an increase in yield in three of the five years (1995, 1996 and 1997) and a decrease in the other two years. In all five years, the application of both seed dressing and foliar spray resulted in yield increase. Despite higher yields obtained from some insecticide treatments, the cost of the insecticide was never recovered from the increase in yield and there was no benefit whatsoever in controlling RWA with insecticides on Gariep.

DISCUSSION AND CONCLUSIONS

The data from this trial indicate that insecticide treatment on resistant Gariep is not economically justifiable as the cost of the insecticide and application thereof was not recovered. The decline in yield associated with insecticidal seed-dressing seems incongruous. This can possibly be explained by a delay in the induction of the RWA resistance reaction caused by RWA feeding due to the fact that the plant is kept aphid free until a later and possibly more sensitive life stage. Van der Westhuisen and Pretorius (1995) showed that biochemical and physiological changes are induced in resistant Tugela-DN, containing gene *Dn1*, by RWA feeding. Resistant plants were able to retain a steady level of chlorophyll content in contrast to the dramatic reduction characteristic of infected, susceptible plants. During the time needed for the resistance reaction to be 'switched on', damage may occur.

The yield loss of Gariep associated with insecticide treatment is in direct contrast to the findings of van der Westhuizen and Lampbrechts (2000). They conducted trials over three years in the Bethlehem and Reitz districts of the Eastern Free State, South Africa with the RWA resistant cultivar SST 363 (resistance donor PI 294994). An average increase of 521 kg ha^{-1} was reported when seed-dressing was applied (Table 2) and it was concluded that the use of Gaucho® on this cultivar was an economically justifiable practice. Tolmay *et al.* (1997) also found a significant increase in yield when the resistant cultivar Gamtoos-DN, with the *Dn1* gene, was treated with imidacloprid. The question that needs to be answered is one of economics and in instances where insecticide treatment increases yield, is the cost of the insecticide relative to the income

the producer receives per hectare. In addition to fluctuating wheat prices and ever increasing input costs another variable that influences the yield of resistant cultivars is the RWA infestation level in the particular field. This is unfortunately a very unpredictable variable and the only way farmers can determine the level of RWA infestation in their fields is by means of regular field scouting.

Contradictory findings such as the results presented here make it difficult to give a general answer to the question of whether it is necessary to apply insecticides to RWA resistant cultivars. It must be remembered that genetic resistance to a pest is a relative phenomenon and that the expression of a resistance gene will differ in different genetic backgrounds. Therefore all resistant lines cannot and do not possess the same level of resistance. Despite this and the variable influence of unpredictable RWA infestation levels, the benefit of using resistant cultivars to control insect pests such as the Russian wheat aphid is high, as farmers purchase insect control "inside" the seed they buy. Resistant cultivars offer a dramatic increase in yield compared to susceptible cultivars (Marasas *et al.*, 1997). The host plant resistance works throughout the season and therefore complex decisions such as choosing an insecticide, determining the correct dosage, calibrating sprayers and timing the spray application to ensure safe and effective control are not a problem.

Trials to determine the efficacy of genetic resistance compared to insecticide control are both time consuming and expensive and it is impractical to attempt to collect data for each of the ever growing number of RWA resistant cultivars that becomes available in the market. The solution to this dilemma probably lies in the characterization of the level of resistance in the resistant cultivars. A field study is presently underway to rank resistant cultivars by their level of resistance expression and it is hoped that this data will answer many of the questions being asked.

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Questions and Answers:

J.D. Theunissen: Is there a difference in standard resistance between xylem and phloem as represented in the EPG graph?

Answer: The different waveforms seen in the electro-penetration graph (EPG) are generated by impedance in the electrical circuit. Xylem and phloem give different waveforms with different frequencies, but the frequencies shown in the xylem and phloem are more related to the ingestion of plant sap by the aphid than to the structure of the vascular tissue, although this does have an influence.

Colin Wellings: You suggested that you can identify several genes for resistance, based on phenotype. Have you been able to confirm this by genetic analysis and do you have strategies for combining genes?

Answer: The genes cannot be distinguished phenotypically; the information we have is based on inheritance of resistance and allelic studies. Combining genes without being able to mark them is difficult and can only be confirmed by test crossing which is a long and tedious process. We are combining genes but will only use the test cross method of confirmation on lines to be released as we do not have the capacity to do test crosses in the breeding process.

Harjit Singh: In the absence of biotypes, molecular markers may be useful to pyramid different genes for resistance. Have you tried any molecular markers for this purpose?

Answer: Yes, we have tried microsatellite markers + RAPD PCR markers but we face the problem of background effect while using these in breeding materials. Some preliminary markers have been identified, but none are as yet being used in our program.

Temam Hussien: What is the source of resistance of your materials?

Answer: Resistance originates from Iran, Iraq, Afghanistan, Bulgaria and other countries in this region. A lot of the resistance is in bread wheat *T. aestivum*.

Ravi P. Singh: What is the role of seed treatment using systemic insecticides in RWA control?

Answer: Seed treatment (Gaucho® and Cruiser®) is very effective for RWA control on intermediate and spring types of wheat. Both insecticides keep plants (resistant or susceptible) clean of aphids but input costs are not always recovered on resistant cultivars. Using seed-dressing on winter wheat, planted early in the season, is also not advisable as the effect of the insecticide is only for a limited time span and it may be that the aphids only infest the crop after the seed-dressing has stopped working.

Mohamed Salih Mohamed: Could resistance genes to Russian Wheat Aphids be effective against other aphid species, e.g., green bug or black bug?

Answer: Unfortunately not. The RWA resistance only works against RWA. Some resistance to other aphids particularly *S. graminum* and to *R. padi* (i.e., wheat with high hydroxamic acid) is available.

Hussien Mansoor: Have you observed the effects of herbicides on the introduced predators?

Answer: No, this is work that still needs to be done, and is probably of importance as weeds may act as refugia for natural enemies of the RWA.

M. Kinyua: Was there a test of significance of differences in yield between treated and untreated?

Answer: Yes, an ANOVA was done and it was found that there is a significant difference between the yield of treated and untreated (control) plots; the control giving significantly higher yield.

M. Kinyua: Why the consideration about the switch-on mechanism, since there was control of aphids by the chemicals?

Answer: On Gaucho-treated wheat, RWA did infest the wheat later in the season. The wheat was not kept RWA-free for the whole growing season. After infection, Gaucho-treated wheat gave a lower yield than untreated Gariep.

Ravi P. Singh: Does Gaucho have any influence on plant growth in the absence of RWA?

Answer: No, not a negative effect. Gaucho actually stimulates growth and in total absence of RWA it has a positive effect on yield, not necessarily a significant effect.

M.A. Mahir: Is it possible that Gaucho has no effect on controlling RWA because it has a short persistence and by the time the RWA appears it was gone?

Answer: Gaucho is effective for around 100 days. During this time, the control treatment (no chem. control) will be infested by aphids, but plants treated with Gaucho will be clean. After this protected period, plants treated with Gaucho also become infected with RWA – possibly too late to switch on the resistance gene.

Table 1. **Yield (t/ha), hectoliter mass (kg/hl) and benefit of insecticide control of RWA using an imidacloprid WS seed-dressing (Gaucho®, 140 g ai per 100 kg seed), a foliar spray of a demeton-S-methyl EC / Parathion EC mixture (125 g ai ha^{-1} + 325 g ai ha^{-1}) at Zadoks GS 30 and a combination of both on the resistant cultivar wheat Gariep.**

Year	Treatment	Yield (t/ha)	HLM (kg/hl)	Wheat Price # (ZAR*/ton)	Income (ZAR/ha)	Difference in income compared to Gariep alone	Benefit of control (difference in income - control cost)
1994	Gariep	1.681	76.0	837.25	1407.42		
	Gariep + Gaucho®	1.565	76.7	837.25	1310.30	-97.12	-211.12
	Gariep + Spray	1.620	75.7	824.50	1335.69	-71.73	-285.73
	Gariep + Gaucho® + Spray	2.026	78.2	837.25	1696.27	288.85	-39.15
1995	Gariep	2.323	72.1	550.00	1277.65		
	Gariep + Gaucho®	2.255	72.3	550.00	1240.25	-37.40	-151.4
	Gariep + Spray	2.607	71.6	550.00	1433.85	156.20	-57.8
	Gariep + Gaucho® + Spray	2.809	72.4	550.00	1544.95	267.30	-60.7
1996	Gariep	2.805	76.2	837.25	2348.49		
	Gariep + Gaucho®	2.589	75.3	824.50	2134.63	-213.86	-327.86
	Gariep + Spray	2.471	74.9	824.50	2037.34	-311.15	-525.15
	Gariep + Gaucho® + Spray	2.534	75.2	824.50	2089.28	-259.20	-587.2
1997	Gariep	2.155	74.8	824.50	1776.80		
	Gariep + Gaucho®	1.982	74.5	824.50	1634.16	-142.64	-256.64
	Gariep + Spray	2.203	74.7	824.50	1816.37	39.58	-174.42
	Gariep + Gaucho® + Spray	2.351	74.8	824.50	1938.40	161.60	-166.4
1998	Gariep	2.403	79.1	850.00	2042.55		
	Gariep + Gaucho®	2.252	79.8	850.00	1914.20	-128.35	-242.35
	Gariep + Spray	1.924	79.9	850.00	1635.40	-407.15	-621.15
	Gariep + Gaucho® + Spray	2.428	79.7	850.00	2063.80	21.25	-306.75

Wheat price and control costs as for 1998 season.

* One US$ = ± ZAR 6.1 (South African Rand).

Table 2. **Yield of RWA resistant SST 363 with and without an imidacloprid WS seed-dressing (Gaucho®, 140 g ai per 100 kg seed) in Bethlehem and Reitz from 1996-1998 (from Van der Westhuizen and Lamprechts, 2000. Reproduced with permission of the authors).**

Year	Treatment	Yield Bethlehem (t/ha)	Yield Reitz (t/ha)
1996	SST 363	2.882	3.834
	SST363 + Gaucho®	3.366	4.333
1997	SST 363	2.250	2.206
	SST363 + Gaucho	2.701	2.817
1998	SST 363	2.792	1.628
	SST363 + Gaucho	3.466	2.040

RUSSIAN WHEAT APHID RESISTANT WHEAT CULTIVARS AS THE MAIN COMPONENT OF AN INTEGRATED CONTROL PROGRAM

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ABSTRACT

In 1978, when Russian wheat aphid was first recorded on wheat in the Free State Province of South Africa, little information regarding the control of this devastating pest was available. Large-scale use of insecticides was the order of the day for many years, but now, after concerted research efforts, farmers are planting resistant cultivars to control this pest. The question is whether these cultivars will provide durable control of Russian wheat aphid. This paper discusses strategies and methods that are being used in breeding for durable resistance. In addition to host plant resistance, other control options, such as biological control using natural enemies like parasitoids and predators as well as entomopathogenic fungi, are being explored in order to integrate them with resistant cultivars to provide an effective and environmentally sound integrated control program for this pest.

INTRODUCTION

The Russian wheat aphid (RWA), *Diuraphis noxia,* is the most economically important pest of wheat produced under dryland conditions in the summer rainfall region of South Africa, causing extensive damage annually (Du Toit, 1992). The RWA, a small grey-green aphid, feeds on the adaxial surface of young leaves. Salivary toxins injected into the plant as the aphid feeds cause the degeneration of plant membranes and chloroplasts resulting in longitudinal yellow and whitish streaks on the leaves. Aphid feeding also causes the leaves to roll closed providing the aphid with a safe environment, protected from desiccation, natural enemies and insecticidal contact sprays. Damage to wheat crops can be limited by the use of systemic insecticides, but the cost can be prohibitive especially where harsh climatic conditions reduce the efficacy of the insecticides (Du Toit, 1988; 1992). World-wide the use of insect-resistant cultivars is seen as one of the most desirable alternatives to insecticides because of their low cost and environmentally friendly action (Burton *et al.*, 1991; Quisenberry and Schotzko, 1994).

In South Africa, RWA resistant cultivars have been developed through a concerted research effort and are now a key component of an integrated control strategy against RWA in both commercial and small-scale production situations. To prevent yield losses, RWA populations must be maintained under the economic threshold level through manipulation of the agro-ecosystem and the use of available pest control options. Resistant cultivars dramatically reduce the number of aphids present in the field by inhibiting aphid growth and reproduction (Tolmay and Maré, 2000). The presence of natural enemies in the field further contributes to the control of aphids by preventing the rapid increase of RWA when conditions become

favorable. In this way RWA are prevented from reaching economically damaging populations thereby avoiding the necessity for curative insecticide applications.

MATERIALS AND METHODS

The approach to controlling RWA in South Africa is to use host plant resistance in the form of resistant wheat cultivars to dramatically reduce RWA populations in the field. Natural enemies including predators, parasitoids and entomopathogenic fungi control the remaining aphids. In circumstances where RWA populations become very large, insecticidal application is used as a curative measure. A short description of each component included in the integrated RWA control program follows.

Russian wheat aphid resistant cultivars

Resistance to RWA in *Triticum aestivum* was first identified by Du Toit (1987), and RWA resistance genes have since been transferred to commercial wheat cultivars through a backcrossing program at the Small Grain Institute (SGI) (Small Grain Institute Technology Report, 1996). The first RWA resistant wheat cultivar was released in South Africa in 1992. At present there are 15 RWA resistant cultivars available to control this aphid in the Free State Province. Different sources of resistance were used during the development of these cultivars and although no exact data are available it is possible that as many as four or five different resistance genes may be employed. It is estimated that these cultivars are planted on more than 70% of the wheat producing area. Acceptable yields have been obtained from these cultivars (Marasas *et al.*, 1997). A number of different sources of plant resistance to RWA have been reported in bread wheat (Harvey and Martin, 1990; Quick *et al.*, 1991; Smith *et al.*, 1991; Souza *et al.*, 1991; Baker *et al.*, 1992; Du Toit, 1992; Formusoh *et al.*, 1992; Porter *et al.*, 1993). Initially, five sources of resistance were used by the Small Grain Institute; namely PI 137739, PI 262660, PI 294994, Aus 22498 and CItr 2401. Backcross breeding was used to transfer this resistance into eight well adapted South African cultivars; namely 'Tugela', 'Betta', 'Molopo', 'Karee', 'Kariega', 'Letaba', 'Molen' and 'Palmiet'. During the backcross breeding process, plants were screened for resistance to RWA in a greenhouse bioassay. Though a tedious method, screening plants using live aphids has proven to be a reliable technique to identify resistant plants and will be used until such time as reliable genetic markers become available to assist selection of plants containing the resistance gene(s). The presence of resistance in the cultivars leads to a reduction in both the percentage of infested tillers and the number of RWA per infested tiller. Furthermore the leaves of the resistant cultivars do not roll closed, leaving RWA exposed on the leaf surface. This characteristic makes it possible to use natural enemies of the RWA to support the resistant cultivars.

Natural enemies

Natural enemies of RWA are used to support the resistant cultivars. The small populations of RWA on resistant cultivars seldom cause economic damage but natural enemy control of these aphids protects the resistance genes in the cultivars by reducing the possibility of a resistance breaking biotype of the aphid occurring. Seven species of ladybird predators, four species of parasitic wasps, one species of predatory fly, two species of hemipteran predators and six species of entomopathogenic fungi are known to be natural enemies of cereal aphids in South Africa (Aalbersberg *et al.*, 1988; Hatting *et al.*, 1999; Hatting *et al.*, 2000; Prinsloo, unpublished data).

One parasitic wasp, *Aphelinus hordei*, was introduced to South Africa from the Ukraine in 1991. The adult parasite is approximately 1mm in length and black in color with yellow legs. After mating, the wasp female lays an egg inside an aphid. The larva feed on the internal organs of the aphid resulting in the aphids' death. The larvae secrete a substance that hardens the aphids' skin turning it black in color. This blackened aphid is called a mummy and a few days after the mummy is formed, an adult parasitoid emerges from it. Each female wasp is able to lay in excess of one hundred eggs during her adult life of about ten days. *A. hordei* enters a resting stage similar to hibernation from April to August each year.

Of the six entomopathogenic fungal species known to infect cereal aphids under field conditions in South Africa the entomopathoralean *Pandora neoaphidis* is considered the most important. The spores of fungal pathogens coming into contact with an aphid will germinate under favorable conditions, penetrate the aphid and cause disease. Diseased aphids become sluggish, stop feeding and die within two to five days. Fungal growth covers the aphid cadaver giving it a puffed brick-brown or white appearance (depending on fungal species). The fungus then produces spores, which may come into contact with other aphids in the vicinity to again cause infection, disease and ultimately death. The spores of certain fungal species can be mass produced and formulated to produce a myco-insecticide. Presently two indigenous fungal species are being evaluated at the SGI for use as myco-insecticides against cereal aphids.

Chemical Control

Insecticide application for the control of RWA is predominantly used on susceptible cultivars. More than 15 insecticides are registered for the control of Russian wheat aphid in South Africa, however, application of these products could influence natural enemies of RWA and should therefore be undertaken with care.

DISCUSSION AND CONCLUSION

Six of the 15 RWA resistant cultivars presently available to producers were developed at the Small Grain Institute. The challenge facing breeders now is to ensure that the resistance incorporated into these and other new cultivars is durable. The use of additional control methods in the field such as natural enemies, the promotion of non-season hosts to support natural enemy populations and judicious use of insecticides such as seed treatments on susceptible cultivars assist in achieving this goal. The diverse nature of the South African wheat production region lends itself to the use of different resistance genes in different cultivars. With 19 different cultivars to chose from, 15 with RWA resistance and a possible four to five different RWA resistance genes in use, a patchwork effect is created and it is unlikely that continuous large tracts of cultivars with the same resistance gene will occur. This should reduce the potential for the development of a resistance breaking biotype of the RWA.

Another strategy is the combining of different resistance genes in the same cultivar. This challenge is more difficult because it is not possible to differentiate between RWA resistance sources/genes using phenotypic symptoms. Identifying plants with more than one gene is also very difficult. In order to overcome this problem studies have been undertaken to identify the mechanisms of resistance in specific donor lines so that they can be used to characterize the resistance; the assumption being that different mechanisms will be expressed by different

genes. Contrasting mechanisms include antibiosis (the negative influence of the host plant on the biology of the pest), antixenosis (the non-preference of the aphid for a particular host plant) and tolerance (the plants ability to withstand infestation without being damaged). All three mechanisms have been observed in our germplasm (Tolmay *et al.*, 1999) but no correlation has been observed between field observations and greenhouse mechanism trials. Usually more than one mechanism is present in a resistant genotype, e.g., antibiosis and antixenosis, and thus the reaction of a gene likely depends on the genetic background.

In the search for an indicator with which to differentiate between resistance genes, feeding behavior studies of Russian wheat aphids on different resistance lines have been initiated. With this technique it is possible to identify modifications in feeding behavior caused by resistant lines. Different genes should be uniquely expressed and it may therefore be possible to identify lines that contain more than one resistance gene or have a superior resistance reaction These studies are still in a preliminary stage but seem to show potential, as dramatic differences occur between lines. Whether these differences will translate into useable indicators for selection in the breeding program, however, remains to be seen.

The influence of host plant resistance on natural enemies is another aspect that is receiving attention as it is well documented that the efficacy of parasitoids and predators can be influenced by the host plant of the aphid (Price *et al.*, 1980). During the first experimental release of *A. hordei* in commercial wheat fields in 1994, about 50% of the RWA in these fields were found to be parasitized. In January 1995, parasitoids were found more than 30 km away from the initial release sites. During 1996, further releases were made in the Bethlehem, Ficksburg and Ladybrand districts, where parasitism of up to 72% were recorded. To date, more than three million parasitoids have been released. Surveys in Lesotho during 1999 and 2000 have shown that this parasitoid now occurs on cultivated wheat in the Highlands more than 200km from the nearest release site (Prinsloo, unpublished data). Data from trials performed at the Small Grain Institute to test *A. hordei* parasitism levels of RWA on susceptible 'Betta' and the resistant cultivars 'Betta-DN' and 'SST333' showed that RWA populations were 50% lower on the resistant cultivars than on the susceptible in the absence of parasitoids. In the presence of parasitoids and resistant cultivars, the RWA population declined by a further 50% (Prinsloo *et al.*, 1995) and no negative effect of the host plant on this parasitoid was observed.

The future of the integrated control program for RWA in South Africa is dynamic and it will likely change in the years to come as more natural enemies are imported from the provenance of the RWA. Cultivars with other resistance genes, higher yields and better quality characteristics are likely to be released and will be incorporated into the integrated control program. There is however no doubt that the effective control of this pest with an environmentally sound and economically viable program will contribute to the sustainable production of wheat in South Africa, to the benefit of all.

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DEVELOPMENT OF LINEAR EQUATIONS FOR PREDICTING WHEAT RUST EPIDEMICS IN NEW HALFA, SUDAN

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ABSTRACT

Multiple regression analysis was used to develop equations predictive of the severity of leaf rust (*Puccinia recondita* f.sp. *tritici*) and stem rust (*P. graminis* f.sp. *tritici*) of bread wheat ,and to estimate weekly cumulative urediniospore numbers of both rust species in New Halfa region. Equations were generated for three overlapping periods to identify and quantify biological and meteorological variables which might provide clues of high predictive value for develôpment of disease epidemics. Analysis of the combined data showed that the derived multiple regression models varied with prediction period, prediction duration and rust species. On the whole, progress in time (X_1) invariably significantly contributed to variation observed in rust severity. Other significant variables were found to be components of atmospheric humidity: minimum RH (X_4), maximum RH (X_5), and hours RH > 80% (X_6), followed by maximum temperature (X_3) towards the end of the growing season but for leaf rust only. Minimum temperature (X_2) and wind speed (X_7), generally, did not significantly contribute to variation in rust severity. Simple linear regression analysis of overall disease severity revealed that leaf rust and combined rust exhibited highly significant and positive relationships with progress in time from 15 Jan. to 31 March, whereas stem rust had a non-significant negative relationship. The combined influence of three biological variables, namely progress in time (T), wheat growth stage (GS), and weekly trapped rust spore numbers (WSN), accounted for only 53 and 21.4% of the total variation in leaf rust and stem rust severity (DS), respectively. Studies with mechanical rust spore trapping (MRST) showed that 40 and 53.7% of the total variation in *P. recondita*, and *P. graminis* weekly trapped urediospore numbers (WSN) can be explained by a function involving: progress in time (T), wind direction (WD), and presence or absence of wheat crop (C). Wind direction exhibited a significant (5%-1%) negative effect on *P. graminis*, but non-significant influence on *P. recondita*, WSN. The inclusion of wheat growth stage (GS) in the model did not significantly improve the explanatory power of the function. Analysis of MRST data collected over ten weeks, from 15 Jan. to 31 Mar., indicated that 68.4 and 74.7% of the total variation in *P. recondita* and *P. graminis* weekly trapped spore number (WSN), respectively, can be accounted for by a function involving: progress in time (T), wheat growth stage (GS), and disease severity (DS). The inclusion of wind speed (WS) as a fourth variable in the prediction model significantly (5%) increased the amount of variation with leaf rust, and had no effect on stem rust spore counts.

INTRODUCTION

Stem rust of wheat (*Triticum aestivum*) incited by *Puccinia graminis* Per. f. sp. *tritici* Eriks & Henn., and leaf rust induced by *P. recondita* Rob. ex. Desm. f. sp. *tritici*, are major wheat production constraints in New Halfa region, Sudan. Grain losses approaching 72%, and kernel weight losses of up to 49.6% have been attributed to rust infections (Mohamed, 1995). Epidemic development of stem rust can occur if disease development occurs early in the season, around December (Mahir and Mohamed, 1997). It has been suggested that the location of the Agricultural Production Scheme (15° - 15°15'N, 35°15' - 36° E) at the foot of the Abyssinian Plateau confers favorable environmental conditions for rust disease development and epidemiology. Given favorable environmental conditions and compatible host/pathogen interactions, development and rapid progress of wheat rust epidemics are dependent in part upon: 1) The amount of initial inoculum; 2) The effectiveness of factors influencing size and availability of pathogen inocula (Burleigh *et al.*, 1972). Within a 24-hour period, concentration of airborne rust spores tended to fluctuate with wind velocity, turbulence, dew, rain and storm fronts, as well as, periodicity in spore production (Eversmeyer and Kramer, 1975; Gregory, 1945). Several factors affecting rust development were studied under controlled environments (Chester, 1946).

From the author's point of view, studies on wheat rust epidemics at New Halfa were inadequately investigated and the results insufficiently interpreted (Mahir and Mohamed, 1997). Emphasis within ICARDA's regional programs was placed on following the seasonal development of wheat rust diseases by the date of first appearance of uredinia in the field, and by monitoring rust spore incidence in the air. Data obtained from volumetric spore sampler were usually presented as average numbers of urediospores per cubic meter of air. Except for the work reported by Mahir and Mohamed (1997), no attempt was made to identify and quantify factors affecting urediospore incidence in the atmosphere, and ultimate development of disease epidemics in New Halfa.

With these considerations in mind, linear multiple regression models from biological and meteorological data were developed to determine, if acceptable prediction was possible and, if so, to select the most appropriate variables for the development of working models.

MATERIALS AND METHODS

The Nile Valley and Red Sea Wheat Disease Nursery (NVRSWDN98), and the Bread Wheat Key Location Disease Nursery (KLDN99), modifications from the late Nile Valley and Red Sea Wheat Rust Trap Nursery (NVRSWRTN), were received from the Wheat Rust Program Coordinator, ICARDA/ARC, Egypt. The nurseries consisted of newly released varieties and advanced lines from throughout the region. A second trial representing the Sudanese National Wheat Rust Program was received from the National Coordinator, ARC, Wad Medani, Sudan. All trials were sown 20th November, but received a first irrigation five days latter.

Location of trials, plot size, nitrogen fertilizer dose and application, and irrigation regime were carried out as previously reported (Mahir and Mohamed, 1997).

Observations on disease development and severity, and wheat growth stage, in experimental plots and random farmers' fields, were recorded several times each week during two consecutive seasons, 1997/98 and 1998/99. The 1 to 5 scale wheat crop growth stage was

modified from the Burleigh *et al.* (1972) system. Rust severity estimates were recorded using the modified Cobb scale (Peterson *et al.*, 1948).

Wheat rust spore trapping was conducted using a Burkard 7-day volumetric sampler (Rickmansworth Herts, England) installed with its 2 mm orifice 4 m above ground level to sample air for *P. recondita* and *P. graminis* urediospores. Spore trapping occurred from 20th May until 17th May during seasons 1997/98 and 1998/99. All device operational procedures, specimen examination, and necessary calculations were performed as previously reported (Mahir and Mohamed, 1997).

Instruments used to obtain meteorological data were: maximum and minimum temperature thermometers (Short & Mason Co., London), Oakaton thermohygrograph (Cole-Parmer Instrument Co., Chicago, Illinois), and wind direction and wind speed recording device (Swift Instruments International S.A., Tokyo, Japan).

Analysis of the relationships between rust severity/spore intensity in air, and biological-meteorological variables were made using linear simple and multiple regression techniques . Regression analysis were structured around measures of time, temperature, atmospheric humidity, and wind components. Regression analysis, with disease severity (dependent variable, Y), was applied to the data using various combinations of the following independent variables: progress in time (X_1), minimum temperature (X_2), maximum temperature (X_3), minimum RH (X_4), maximum RH (X_5), hours RH > 80% (X_6), and wind speed (X_7).

Data processing for the development of rust severity estimation models, was done for three overlapping periods, and nine sub-periods to cover the whole wheat growing seasons 1997/98 and 1998/99 (for details, refer to Table 1).

Percent disease severity (DS) data, collected over a period of ten weeks, from 15 January to 31 March, were simultaneously regressed on three biological variables: progress in time (T), wheat growth stage (GS) expressed as integers on a scale of 1 to 5 (1=seedling, 2=tiller, 3=boot, 4=head, and 5=ripe) as modified from Burleigh *et al.* (1972), and weekly trapped rust spore numbers (WSN).

In studies with mechanical rust spore trapping (MRST), the weekly trapped spore number (WSN) was regressed on various combinations of the following independent variables to explore associations: progress in time (T), wind direction (WD) rated as: 1= S, SW, SSW; 2= N, NW, NNW, NE, NNE; wind speed (WS) in mph; absence or presence of wheat crop (C) rated as: 0 and 1, respectively; wheat growth stage (GS) modified from Burleigh *et al.* (1972); and rust disease severity (DS) estimated as percentage (Peterson *et al*, 1948). MRST data subject to analysis were obtained from 33 week records (May to May, next season), and ten week records (15 January to 31 March, same season), for two consecutive seasons, 1997/98 and 1998/99.

RESULTS

In the course of this study, data processing was performed in a series of one hundred linear simple and multiple regression operations for the development of rust severity prediction and rust spore estimation models. Following the computational procedure recommended by Gomez and Gomez (1984), Tables 1 (LR), 2 (SR), and 3 (combined), show independent

variables having partial multiple regression coefficients (means for 1997/98 and 1998/99) with computed t value greater than the tabular t value, up to a 20% level of significance. This suggestion was made because of the increasingly accepted perception of the interdependence within and between environmental and biological factors in nature. This assumption especially holds true in pathological studies where even a slight change in one factor, may alter the effect of other factors on disease development through interaction.

Experimental findings extracted from the information presented in Table 1, 2, and 3, can be summarized in the following points:

- The partial regression coefficients in our working equations varied with, regression term, prediction period, prediction interval, as well as rust species.
- One or more of the coefficients was significant in each individual case.
- By omitting variables with non-significant (P>20%) coefficients, some variables were allowed to enter the model as primary disease determinants.
- With few exceptions, particularly for *P. recondita,* variation in time effectively explained variation observed in disease severity.
- Of the seven regression terms tested, the significant determinants of rust severity were variables associated with atmospheric humidity: minimum RH(x_4), maximum RH(x_5), and hours RH > 80% (x_6).
- A comparison through partial regression coefficients of temperature components indicated that max. temp.(x_3) was often better than min. temp.(x_2) in explaining variation observed in leaf rust (LR) severity. However, with stem rust, and combined rust, max. temp. was always equal to min. temp.
- Generally, multiple regression equations for short and medium term severity predictions, have relatively higher coefficient of determination (R^2) values.
- It is clear from Table 4, that, except for two prediction intervals, 1st February to 14 February, and 17 March to 31 March, leaf rust had significantly (P < 5-0.1%) increased in severity with progress in time. On the other hand, stem rust had very highly significantly (P < 0.1) increased in severity between 15 January and 14 February, and significantly (P < 5-0.1) decreased thereafter.

The combined influence of three biological variables (progress in time (T); wheat growth stage (GS); and weekly rust spore numbers (WSN)) on rust severity was investigated using multiple regression analysis. The estimated multiple regression equations simultaneously relating these three bio-variables to rust severity, are presented below:

$$DS_{LR} = 121.18 + 23.6\ T - 46.65\ GS - 1.74\ WSN\ (R^2 = 0.53)\ (59)$$

$$DS_{SR} = 29.97 - 0.39\ T - 1.37\ GS - 0.19\ WSN\ (R^2 = 0.21)\ (60)$$

The effect of various combinations of four independent variables, one meteorological and three biological, on weekly trapped rust spore numbers (WSN) was studied using multiple regression analysis technique. The estimated multiple regression equations simultaneously relating progress in time (T), wind direction (WD), and presence or absence of wheat crop (C), to weekly spore numbers (WSN), are given below:

$$WSN_{LR} = 5.88 + 0.75^{**} T - 6.87 WD - 1.86 C \ (R^2 = 0.40) \quad (61)$$

$$WSN_{SR} = 29.04 + 2.63^{***} T - 25.91^{*} WD - 5.14 C \ (R^2 = 0.54) \quad (62)$$

When growth stage (GS) of the crop was added as a 4th variable in the model the following multiple regression equations were obtained:

$$WSN_{LR} = 5.94+0.81^{*}T - 7.4WD - 1.51C - 0.32GS \ (R^2 = 0.40) \quad (63)$$

$$WSN_{SR} = 29.98+3.57^{**}T-33.4^{**}WD-0.21C-4.59GS \ (R^2 = 0.56) \quad (64)$$

Two of the four variables evaluated in MRST studies were purposely replaced by another two from the same groups: rust disease severity (DS), and wind speed (WS), instead of (C), and (WD), respectively. The joint effect of three variables, (T), (GS), and (DS), on weekly trapped rust spore number (WSN), was evaluated. The estimated linear multiple regression equations simultaneously relating these three variables to (WSN), are given below:

$$WSN_{LR} = 30.73 + 7.13 T - 13.27 GS - 0.13 DS \ (R^2 = 0.68) \quad (65)$$

$$WSN_{SR} = - 35.18 + 2.04 T + 15.63 GS - 0.17 DS \ (R^2 = 0.75) \quad (66)$$

When wind speed (WS), was added as a 4th variable in the prediction model the following multiple regression equations were obtained:

$$WSN_{LR} = -4.77+3.74 T-6.4GS-0.1 DS+8.77^{*} WS \ (R^2 = 0.87^{*}) \quad (67)$$

$$WSN_{SR} = -33.24+2.17 T+15.3 GS-0.18 DS-0.41WS \ (R^2 = 0.75) \quad (68)$$

Figure 1 illustrates rust spore distribution at New Halfa (values represent May to May weekly mean cumulative spore counts for seasons 1997/98 and 1998/99).

DISCUSSION

Environment is a complex aggregation that includes many factors which must be beyond a minimum threshold for disease development to occur (Eversmeyer and Burleigh, 1970). Therefore, in developing rust severity estimation models, our primary concern was to identify and quantify biological and meteorological variables that crucially affect wheat rust development in New Halfa area, and to see if they could serve as clues for disease epidemics. Such information could be of great importance and would augment utility of breeders' and agronomists' techniques in their attempt to minimize economical crop losses.

In this study, models were developed for partial and entire sets of data. The results obtained suggest that the climatological variables tested appear more useful for short, medium, and long term prediction of leaf rust rather than stem rust disease. Thus, even though rust disease development in New Halfa, is dependent upon primary inoculum from outside, small inputs of urediospores early in the season are all that are needed for rust epidemics development in that area.

It seems likely that the meteorological components associated with atmospheric humidity would have been as effective as the seven variables tested, for mid-season leaf rust development and severity prediction. From the partial regression coefficients summarized in Table 1, emerge ten equations based on minimum RH (X_4), maximum RH (X_5), and hours RH > 80% (X_6), that would predict/estimate leaf rust severity between mid-January and late-February with acceptable level of confidence ($R^2 > 0.60$). The working equations 1,2,5,6 and 10, are super for short term (two weeks) prediction, whereas equations 3,4,9 and 7,8 are useful for medium term (4 wks), and long term (> 6 wks) predictions, respectively (Table 1).

Inspection of the models reported here suggests that mid-season temperature variables (X_2 and X_3) did not help much in explaining variation observed in rust severity. This may be because their direct effect on disease development was negated by the cooling effect of atmospheric humidity. However, as the RH declined, with the advancement of the growing season, maximum temperature appeared as a major component of rust severity prediction equations. Equations based on max. temperature plus one or two atmospheric humidity variables, generated for medium and long term severity prediction toward the end of the growing season, accounted for 52% to 53% of the variation (equations 12-14, Table 1). This finding further supports the above findings that factors associated with ambient humidity offers clues of high predictive value for rust epidemics development in New Halfa area. This result is found in agreement with an earlier study reported by Eversmeyer and Burleigh (1970).

By comparing information presented in Table 2, it could be deduced that, except for the period 15 January to mid February period, climatological conditions were not conducive for stem rust development. This presumption is clearly indicated by the limited number of independent variables in disease severity estimation equations, as well as by the relatively low coefficient of determination (R^2) values. Of the 17 stem rust estimation models, only four short term and one medium term equations gave R^2 values > 0.60, compared to 12 equations for leaf rust, and seven for combined rust estimation.

Moreover, it is clear from Table 4, that both leaf and combined rust significantly increased with progress in time until 16 March, and decreased, but not significantly, thereafter. On the other hand, stem rust significantly increased only until 14 February, and significantly decreased thereafter.

The rationale for using growth stage (GS) of wheat in models for estimating urediospore incidence in air, is that, as the crop matures more rust occurs (Burleigh *et al.*, 1972), and consequently more rust spores are generated. However, studies carried out with MRST at New Halfa clearly indicated that for factors like growth stage, or the presence or absence of wheat crop, do not seem to have clear biological meaning in rust spore incidence prediction models (equations 61 to 64), yielding R^2 values from 40-56. The principal difficulty with relating rust urediospore counts in air to, disease severity, wheat growth stage, and presence / absence of the crop in the field, is that the spore sampler is indiscriminately exposed to spores from endogenous and exogenous sources and the vicissitudes of weather might cause more or fewer spore captures from a given level of infection in the field (Burleigh *et al.*, 1972).

Multiple regression equations involving (T), (GS) and (DS) accounted for 68% and 75% of the total variation in leaf rust (LR) and stem rust (SR) urediospore counts, respectively.

Nevertheless, the inclusion of wind speed (WS) in urediospore prediction models, substantially improved the explanatory power of the function with *P. recondita* by 26.7% (equations 65 and 67), and had no effect with *P. graminis*. This contradictory effect of wind speed on variations in rust species spore counts, could be explained by the fact that, the exceptionally favorable conditions for leaf rust development experienced in season 1997/98 and 98/99, resulted in subsequent generation of *P. recondita* urediospores up to the end of March, that often coincides with high speed wind storms.

It is clear from results obtained that, wind direction significantly (P < 5%-1%) negatively affected *P. graminis* urediospore counts, and had a non-significant negative effect on *P. recondita* spore incidence in the air. This result might suggest that the greater proportion of stem rust primary inoculum is received at New Halfa ahead of the wheat growing season. Consequently, crucial seasonal changes in population dynamics and biology of the initial inoculum of *P. graminis* cannot be ruled out. This hypothesis could be supported by the significant decline in stem rust severity observed early in the season in spite of the fact that weather deviations after mid-February were not drastic. The average environmental data records taken from NHRS micro-meteorology unit for the periods, 15 January to 28 February, and 1 March to 31 March 1998 and 1999, are given below:

Period	max. T °C	min. T °C	max. RH%	min. RH%	Hr RH>80%
15J-28F/98	33.4	14.3	82.8	33.0	2.9
15J-28F/99	32.5	13.6	87.8	36.4	4.6
1M-31M98	38.1	18.9	74.8	32.0	2.8
1M-31M99	35.6	19.2	73.3	32.4	2.7

CONCLUSIONS

The degree of accuracy of the estimated regression equations vary greatly from one data source to another (Gomez and Gomez, 1984). Therefore, evidence might be too sketchy to draw conclusions. Nevertheless, several hypothetical points could arise from the interpretation of the multiple regression equations derived in this study:

- The models presented here are primarily useful in showing the kinds of predictions and effects of various biological and climatological variables which may affect wheat rust epidemic development at New Halfa area, rather than providing working prediction equations.
- Meteorological factors associated with atmospheric humidity are good clues for epidemics development.
- The climatological variables tested appear more useful for predicting incidence of leaf rust rather than stem rust prediction.
- The numbers of urediospores trapped at New Halfa, although related to disease development, cannot be correlated with disease severity.
- Wind speed is a crucial determinant of the variation in *P. recondita* urediospore incidence in air.
- Wind direction accounts for a great proportion of the variation in *P. graminis* spore counts.
- The greatest proportion of *P. graminis* urediospores is received at New Halfa ahead of the wheat growing season.

- Perceptible levels of initial inoculum of both rust species hover over New Halfa between May and November. Since winds, with few exceptions, are predominantly from SW-SSW, during this period every year, therefore, its origin is presumably geographically located likewise.
- There are two qualifications to the urediospore distribution at New Halfa:
  - The curves do not exactly follow patterns associated with local and external production of rust spores.
  - Notably New Halfa, has a tri-modal distribution of urediospores, this finding might suggest the existence of more than one major source of inoculum in the region.
- The prediction system presented in this paper is considered as preliminary, nevertheless, offers a baseline model for future studies in the region.

RECOMMENDATIONS

The following innovative research proposals are strongly recommended:

- The Rust Trap Nursery should be on farm at New Halfa, as early as July, to monitor changes in population dynamics and biology of wheat rust species.
- Future research strategies should focus on:
  - conducting epidemiological studies with the objective of developing methods of identifying potential disease threats early enough to enable using other disease control measures e.g. aerial spraying.
  - support in terms of equipment and facilities.
  - upgrade research skills and capabilities scientists and supporting staff.

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Questions and Answers:

Izzat S.A. Tahir: Wind direction (WD) affects or influences *P. graminis* but not *P. recondita*, while wind speed (WS) influences *P. recondita*. What does that imply regarding sources of spores and the time of their appearance?

Answer: (1) The contradictory effect of WS on spore counts is that the favorable condition for LR development resulted in subsequent generation of LR spores up to the end of the season which often coincides with high speed wind storms. (2) The significant effect of WD on SR spore counts indicates the existence of a major source of SR primary (initial) inocula probably geographically located southwest of New Halfa region and needs to be researched. Also, we can make use of the significant effect of WD on SR spore counts to recommend that the rust trap nursery should be on-farm from early July and that will enable us to monitor for population dynamic changes and biological variability among SR strains.

Wolfgang H. Pfeiffer: Forecasting rust epidemics will depend on the varieties grown, their genetic composition in terms of resistance genes, type of resistance and temperature sensitivity of the resistance gene. When and how are you including these host factors into your model?

Answer: Fortunately, in the Sudan, we have only two wheat varieties for large-scale commercial wheat production. But certainly we have to develop the models as the situation changes concerning genotypes. But how? Will be done in consultation with breeders and statisticians.

Table 1. Partial regression coefficients for prediction of leaf rust disease.

N	Period	x_1	x_2	x_3	x_4	x_5	x_6	x_7	R^2	T
1	15J-31J	0.55			0.22	-0.15	0.90		0.79	S
2		0.51**			0.11	-0.08	0.40		0.74	S
3	15J-14F	1.20***			0.50*	0.32*			0.61	M
4		1.20***			0.52*	0.16*			0.58	M
5	1F-14F	-6.39		-9.80*	2.29	1.24	-3.69		0.69	S
6		-6.38*		-10.20*	2.08*	1.20*	-3.82*		0.68	S
7	15J-28F	1.64***			0.51*				0.80	L
8		1.69***			0.47**				0.80	L
9	1F-28F	2.52***							0.70	M
10	15F-28F	3.09**					1.29*		0.70	S
11	1F-31M	0.40				-0.43	3.78*		0.29	L
12	1F-16M	0.87**		2.61	1.10	-0.66	3.08		0.53	L
13		0.86**		2.86*	1.15*	-0.65	3.06*		0.53	L
14	1M-31M	-1.42		3.78*					0.52	M
15		-1.56**		4.25**					0.31	M
16	1M-16M						4.22		0.66	S
17	17M-31M	-3.48		7.58	2.20*				0.84	S
18		-2.79		4.35*	2.60**				0.73	S
19	15J-31M	0.69***		1.57	0.53		2.67*	-6.04*	0.53	L
20		0.73***		0.80	0.35		1.27	-5.75	0.51	L
21		0.84***					1.45*	-4.80*	0.50	L

N = Equation no.; Period = 15 January – 31 March.
x_1 = progress in time; x_2 = min temp; x_3 = max temp; x_4 = min RH; x_5 = max RH;
x_6 = hrs RH >80%; x_7 = wind speed; T= term; S= short; M= medium; L= long.
*, **, *** Significant at the 5, 1 and 0.1% levels, respectively.

Table 2. Partial regression coefficients for prediction of stem rust disease.

N	Period	x_1	x_2	x_3	x_4	x_5	x_6	x_7	R^2	T
22	15J-31J	3.02***		-4.69		-0.38			0.90	S
23		3.12***		-3.60		-0.08			0.80	S
24	15J-14F	1.42***	-2.95		-0.56				0.64	M
25		1.42***	-1.71		-0.77				0.59	M
26	1F-14F	-5.00							0.43	S
27	15J-28F	0.34			0.73*				0.17	L
28	1F-28F	-1.15*	-3.04						0.40	M
29		-0.92**	-2.39*						0.31	M
30	15F-28F	-2.48					3.71		0.56	S
31	1F-31M	-0.44**							0.39	L
32	1F-16M	-0.50**							0.43	L
33	1M-31M				0.91*	-0.40*		-4.53	0.52	M
34					0.88**	-0.33***		-6.33**	0.49	M
35	1M-16M				1.22	-0.42			0.70	S
36					1.25**	-0.31**			0.65	S
37	17M-31M				0.99				0.58	S
38	15J-31M					-0.30	1.63		0.14	L

For notes: see Table 1.

Table 3. Partial regression coefficients for prediction of combined leaf and stem rust severity.

N	Period	x_1	x_2	x_3	x_4	x_5	x_6	x_7	R^2	T
39	15J-31J	3.57**		-5.81*		-0.53*	2.69		0.93	S
40		3.78**		-6.71**		-0.51*	2.85**		0.92	S
41	15J-14F	2.62***	-3.30						0.75	M
42		2.57***	-1.37						0.70	M
43	1F-14F		-5.92						0.44	S
44	15J-28F	2.12***				-0.25			0.79	L
45		2.03***				-0.26			0.78	L
46	1F-28F	1.37							0.41	M
47	15F-28F	0.61					5.00		0.54	S
48	1F-31M				0.88*	-0.69	4.47		0.17	L
49					0.57	-0.67*	4.45**		0.14	L
50	1F-16M				1.02	-0.70	3.61		0.22	L
51						-0.76*	4.42*		0.12	L
52	1M-31M	-1.63*		3.74					0.41	M
53		-1.61**		3.55					0.25	M
54	1M-16M						4.52		0.43	S
55	17-31M				2.99				0.73	S
56	15J-31M	0.65**				-0.65*	4.41**	-7.06	0.42	L
57		0.58**				-0.70*	4.46**	-7.67*	0.41	L
58		0.60***				-0.62*	4.26**		0.37	L

For notes: see Table 1.

Table 4. Regression coefficients and coefficients of determination (R^2) obtained from regression of disease severity (y) on progress in time (x).

Period	LR		SR		LR + SR		T
	x_1	R^2	x_1	R2	x_1	R^2	
15J-31J	0.54***	0.64	2.22***	0.72	2.76***	0.78	S
15J-14F	1.11***	0.51	1.33***	0.46	2.44***	0.70	M
1F-14F	0.99	0.08	0.81	0.04	1.80	0.12	S
15J-28F	1.70***	0.78	0.32	0.08	2.03***	0.77	L
1F-28F	2.28***	0.66	-0.72*	0.15	1.56***	0.37	M
15F-28F	3.14**	0.59	-1.03*	0.29	2.11*	0.32	S
1F-31M	0.51**	0.14	-0.47***	0.32	0.05	0.00	L
1F-16M	1.20***	0.40	-0.64***	0.32	0.56*	0.11	L
1M-31M	-0.16	0.00	-0.29	0.08	-0.44	0.03	M
1M-16M	3.09*	0.35	-1.44**	0.46	1.65	0.12	S
17M-31M	-2.18	0.24	0.45	0.05	-1.98	0.16	S
15J-31M	0.82***	0.45·	-0.13	0.04	0.70***	0.30	L

For notes: see Table 1.

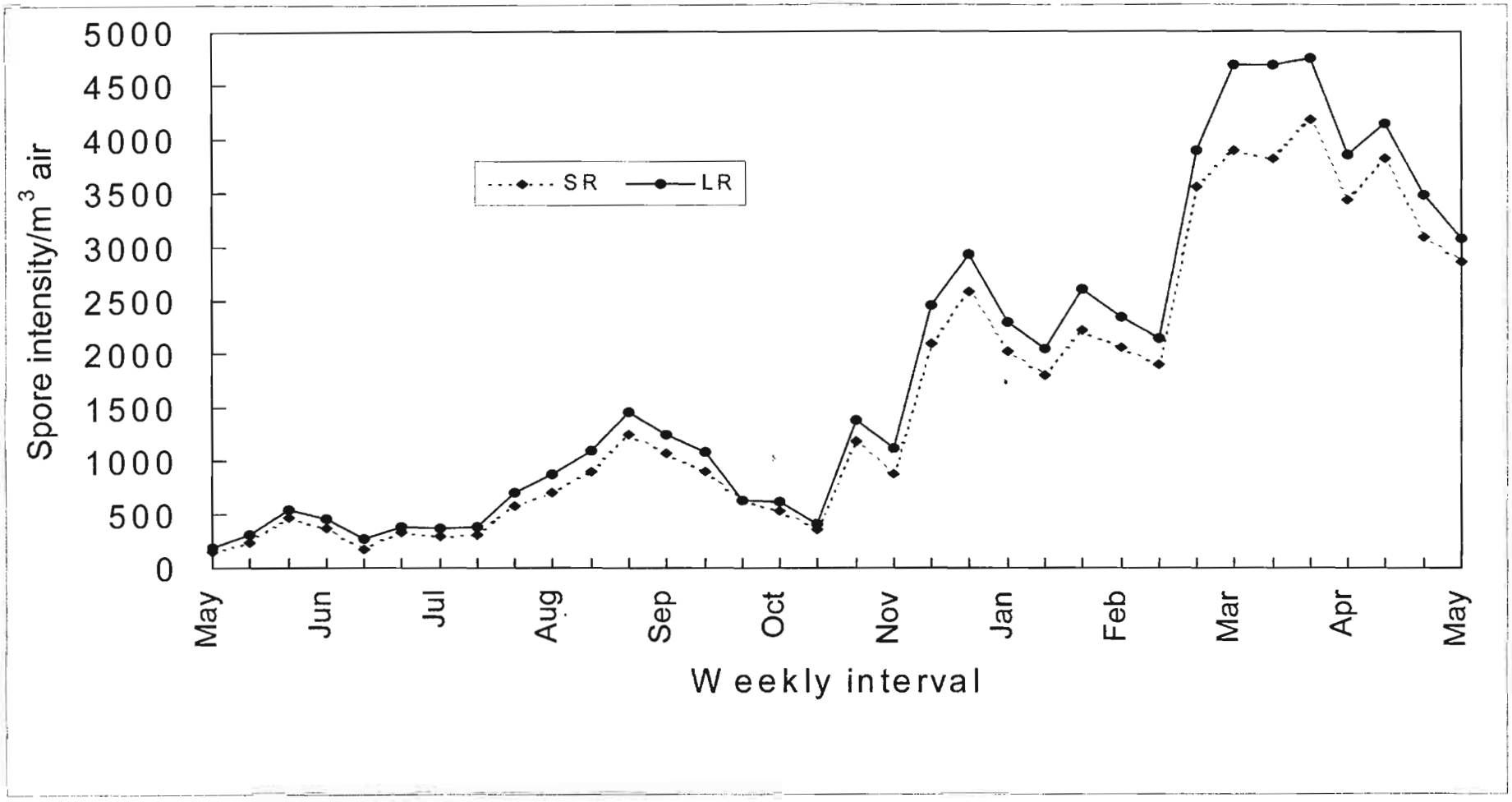

Figure 1. Rust spore distribution, New Halfa.

BREEDING FOR DISEASE RESISTANCE IN WHEAT IN UGANDA

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ABSTRACT

Yellow and stem rust (caused by *Puccinia striiformis* and *P. graminis*, respectively) and Septoria leaf blotches (caused by *Septoria* spp.) are among the wide range of wheat diseases that constrain wheat production in the highlands of Uganda. Screening for resistance to these diseases relies on natural infection in the field. A study to determine the potential yield losses due to yellow rust was carried out at Kalengyere, a hot spot for yellow rust. The performance of F_1s and F_2s derived from a complete 8 x 8 diallel of bread wheat lines was evaluated in fungicide-treated and untreated plots in 1995 and for the F_2s in 1996. The fungicide treatment controlled yellow rust and Septoria leaf blotches. A yield loss of 83% was attributed to all foliar diseases, averaged over the F_1s and F_2s during the test period. A yield loss of 25% was attributed specifically to yellow rust. The importance of stem rust emphasized during the 1998A season when 457 and 280 lines, comprising the PCYR/LR nursery and the 9thHigh Rainfall Wheat Screening Nursery (HRWSN) respectively, were screened at Kalengyere Research Station. During this season, stem rust of wheat was the most important disease. A total of 33 and 21 lines were selected from the PCYR/LR and 9th HRWSN, respectively, and had infection scores ranging from 'T' to '5MS' for stem rust. During the same season, a breakdown of *Sr*31 was detected. During testing of these selections in the following season, 1999A, when the prevalent disease was yellow rust, 80% of the selections had a yellow rust reaction range of 'TR' to '20MS'. These results indicate that screening for field disease resistance over seasons can be a useful tool for the identification and development of genotypes with resistance to a wide range of diseases.

INTRODUCTION

Wheat in Uganda is a rain-fed crop grown in the highlands (1800-2400 m a.s.l.) of the southwest and on the slopes of Mt. Elgon in the east. Low temperatures averaging 16°C and relatively high bi-modal rainfall characterize these areas. In the southwest, 480 mm and 750 mm of rain are received in the March-August (Season A) and September-March (Season B) respectively. Likewise in the east, Season A receives 470 mm while season B receives 560 mm of rain. Relative humidity averages 70% over these areas. These environmental conditions favor the occurrence of many wheat diseases. At the higher altitudes in the southwest, stripe rust (*Puccinia striiformis* Westend) and speckled leaf blotch (*Septoria triticii*) are most prevalent. However, in addition, in the recent past, stem rust (*Puccinia graminis*) has been observed to occur. Other diseases in the wheat growing areas of Uganda include leaf rust caused by *P. recondita* and *Fusarium* head blight caused by *Fusarium* spp.

The small size of the wheat production areas in Uganda (< 5000 ha) does not merit a full scale breeding program that includes hybridization and the selection of segregating populations. Our approach is to introduce a wide range of lines from countries and/or regions (and especially from CIMMYT) with similar growing conditions. These lines are then screened under local conditions for adaptability and disease resistance. Selection of promising lines for further testing in yield trials is done during this evaluation. This paper highlights some of the salient features that have been experienced in the program in the past few years.

MATERIALS AND METHODS

Assessment of Yield Loss due to Diseases

Genotypes derived from an 8 x 8 diallel crossing scheme of bread wheat genotypes were used in this study. The parents were selected from CIMMYT-derived material according to their host response to yellow rust at Kalengyere, a location with high incidence of this disease (Wagoire, 1997). This germplasm has been bred for wide adaptation, including resistance to pests and diseases (Braun *et al.*, 1997). The lines Buri, Kenya Chiriku and ESDA/LIRA were rated as resistant to yellow rust reaction, while the lines VEE/JUP73/EMU"S"/GJO"S" and Attila were recorded as moderately resistant and moderately susceptible, respectively. The other 3 lines were rated as susceptible to yellow rust. The performance of F_1s and F_2s derived from a complete 8 x 8 diallel of these lines was evaluated in fungicide-treated (FT) and untreated (NT) plots at Kalengyere in southwestern Uganda during 1995 season B and, for the F_2s only in 1996 season A. A split-plot design with 2 replicates was used. Fungicide treatment was the main plots while the wheat lines were the subplots. The experimental plot (subplot) for the F_1s consisted of 2 rows of 1.5 m length and 0.3 m inter-row spacing whereas for the F_2s, the experimental plots consisted of 2 rows of 5 m length and 0.3 m inter-row spacing. In all experiments spacing between plants was 0.15 m and nitrogen was banded at planting at a rate of 50 kg ha^{-1}.

The fungicide "FOLICUR 250 EC" [250 g l-1 terbuconazole] which the manufacturer recommends for the control of small grain stem and foliar diseases was used. It was applied as a foliar spray using a knapsack sprayer at a rate of 150 ml ha^{-1} of active ingredient. Application was made at Zadok's growth stage (GS) 37 and also at GS 69 (Roelfs *et al.*, 1992).

Data taken included yellow rust incidence and severity using the modified Cobb scale (Peterson *et al.*, 1948), and yield in grams per plot. Analyses of variance were carried out using sub-plot means (Mead *et al.*, 1993). The data were analyzed separately for both the F_1 and F_2 generations. Further, comparisons were made among the crossing schemes i.e., Resistant x Resistant (R x R), Resistant x Susceptible (R x S) and Susceptible x Susceptible (S x S) crosses.

Screening of Wheat Nurseries

Table 1 shows the introductions received from CIMMYT as international nurseries. All nurseries were planted by hand in 2 row-plots, 30 cm apart at a seed rate of 100 kg/ha. Fertilizer was banded at the rate of 50 N and 50 P_2O_5 kg ha^{-1}.

Plots were weeded by hand at approximately four and eight weeks after planting and bird scarers were employed to control bird damage. Harvesting, threshing and winnowing were carried out by hand.

Selections made in the first season of screening are evaluated further in the following season and disease selection pressure that exists in that particular season is used in selection.

The nurseries were observed periodically throughout each season for disease reaction for mainly yellow rust and stem rust, spot blotch and yield.

RESULTS AND DISCUSSION

Assessment of Yield Loss due to Diseases

The performance of the genotypes and their mean yellow rust scores at Kalengyere for the F_1s and F_2s are shown in Table 2. There was a high infection of yellow rust as shown by the high coefficient of infection (CI) of the S x S group in the control plots. Within the fungicide treated plots, no yield differences occurred in the F_1s. In the F_2s, significant differences in yield existed between the groups in the 1995A season but not in the 1996A season. In the control plots, significant differences occurred between the groups for yellow rust and, so were the corresponding yields.

This data can be used to apportion yield losses to the different prevalent diseases (Wagoire *et al.*, 1998). The difference in mean yield between the fungicide treated and untreated plots of the susceptible material, that is the S parents and S x S crosses, represents the loss caused by diseases which can be eliminated by chemical control. In the 1995 B season, this loss was 85% for the F_1s and 87% for the F_2s, while for the F_2s in the 1996 season A it was 77% (Table 4). Yield loss due to foliar diseases other than yellow rust were calculated from the difference between fungicide treated and control groups for R parents and R x R crosses. These losses amount to 65, 73, and 37% for the F_1s and F_2s in the 1995 season B and in the F_2s in the 1996 season A, respectively. Finally, the yield difference in untreated plots between R x S and S x S crosses, which are half-sib families, provides an estimate of the gain attributable to yellow rust resistance. Averaged over the three trials at Kalengyere (Table 4), the estimated yield increase due to yellow rust resistance is 138%.

Screening nurseries

During 1998B season, stem rust constituted the major screening criteria. High levels of infection were scored on material known to carry the 1BL-1RS chromosome translocation containing the *Sr31* gene for resistance to stem rust, virulence to *Sr31* was suspected. Accordingly, samples from some of these lines (Table 4) were tested for identification of the prevailing biotype (Pretorius *et al.*, 1999). All the lines tested for *Sr31* invariably showed a breakdown in resistance to this gene. This situation is worrying, as it is known that wide spread resistance to stem rust in wheat is conferred at least in part to the gene *Sr31*. However, while many wheat programs such as CIMMYT have been preparing for such a situation, the evaluation of developed/derived lines across diverse sites is crucial in detection of such shortfalls. It is also important to note that of the about 30% selections made that showed adequate levels of resistance to stem rust, 10 lines also showed good resistance to yellow rust in 1999A season (Table 5). These lines were used to constitute a preliminary yield trial to

assess for other attributes such as yield.

From the foregoing, it is evident that stem and yellow rust and Septoria leaf blotches constitute some of the biotic constraints to wheat production in Uganda. Further, Kalengyere research station is a hot-spot for the aforesaid diseases. However, the occurrence of these diseases is unpredictable as evidenced from the seasonal variation in their occurrence. Therefore, testing of lines both newly developed and already in production around the world needs to be carried out continuously in such hot-spots. In this way, researchers will keep ahead of impeding disasters that arise from development of new disease biotypes.

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Questions and Answers:

M.A. Mahir: If using fungicide (against other foliar diseases) with R x R crosses and it gives a CI value as low as 0-13, why don't you go for fungicide against YR itself?

Answer: Most wheat farmers in Uganda are small-scale and recommendation of fungicide would not be feasible.

Sewalem Amogne: What are the reasons for the change in the importance of stem rust over time at your research site?

Answer: No definite answer, but could be due to the appearance of a new pathotype of stem rust.

Table 1. Nurseries screened in 1998B and 1999A seasons.

Site	Season	Nursery*	No. of entries	No. of selections	% selections
Kalengyere	1998B	PC YR/LR RG	457	34	7.4
Kalengyere	1998B	9th HRWSN	135	20	14.8
Kalengyere & Buhweju	1998B	19th ESWYT**	50	21	42.0
Kalengyere	1999A	Selections from PC YR/LR RG	34	5	14.7
Kalengyere	199A	Selections from 19th HRWSN	20	5	25.0

* PC YR/LR RG = *Parcella Chica* for Yellow rust/Leaf rust material; HRWSN = High rainfall Wheat Screening Nursery; ESWYT = Elite Spring Wheat Yield Trial.

** The selections made from this nursery, were only at Buhweju where there was no disease pressure. Otherwise, at Kalengyere all the 50 entries were highly susceptible to yellow rust.

Table 2. Means for yellow rust coefficients of infection and grain yield (g m^{-2}) for F_1s and F_2s of a complete 8 x 8 diallel at Kalengyere during 1995B and 1996A.

Cross	N	Yellow rust score (CI)						Grain yield (g m^{-2})					
		F1s		F2s				F1s		F2s			
		1995B		1995B		1996A		1995B		1995B		1996A	
		FT	NT	FT	NT	FT	NT	FT	NT	FT	NT	FT	NT
R x R	16	0.13	1.54	0.15	2.30	0.71	2.29	415.3	146.6	212.2	56.3	215.2	134.8
R x S	32	1.76	13.67	1.02	16.28	1.48	10.26	403.4	128.5	211.4	50.6	201.3	89.1
S x S	16	5.51	69.04	2.76	65.62	7.20	59.60	362.2	55.7	174.5	23.3	175.9	40.3
L.S.$D_{0.05}$		10.59	20.41	4.56	15.83	9.92	22.28	195.2	96.4	163.0	70.1	150.5	100.0
F-test		***	***	***	***	***	***	ns	***	***	***		

N = Number of means to calculate group means; FT = Fungicide treated; NT = Not treated with fungicide; ns = not significant;
* = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

Table 3. Yield gains and losses at Kalengyere.

	% loss due to			
Generation/ Season	**AFD**	**AFD-YR**	**YR**	**% gain from YR resistance**
F_1 95B	85	65	20	148
F_2 95B	87	73	14	125
F_2 96A	77	37	40	141
Mean	83	58	25	138

AFD = All foliar diseases.
YR = Yellow rust.

Table 4. Test lines which were sampled for stem rust biotype identification.

PCYR/LR No.	**Cross and Selection History**	**Stem rust reaction**
223	PVN//CAR422/ANA/3/KAUZ*2/TRAP//K CG62-099Y-099M-3Y-2M-4Y-0B	60S
269	PVN//CAR422/ANA/5/BOW/CROW//BU CG65-099Y-099M-8Y-6M-4Y-OB	5MS
297	PVN/YACO/3/KAUZ*2/TRAP/KAUZ CG68-099Y-099M-22Y-2M-3Y-0B	80S
298	PVN/YACO/3/KAUZ*2/TRAP/KAUZ CG68-099Y-099M-22Y-2M-2Y-0B	90S
359	CAR422/ANA//PBW65/3/KAUZ*2/TRAP//KAUZ CG90-099Y-099M-14Y-4M-5Y-0B	2S
365	CAR422/ANA//PBW65/3/KAUZ*2/TRAP//KAUZ CG90-099Y-099M-39Y-4M-1Y-0B	60S
378	TRAP#1/YACO//BAV92 CG94-099Y-099M-16Y-1M-5Y-0B	80S

Table 5. Ten lines with very good resistance to stem and yellow rust during 1999 season B.

No.	Name/Pedigree	Source	Stem rust score	Yellow rust score
1	SNI/PBW65/3/KAUZ*2/TRAP//KAUZ CG36-099Y-099M-27Y-3M-5Y-0B	PCYR/LR-119	TR	2MR
2	SNI/PBW65/3/KAUZ*2/TRAP//KAUZ CG36-099Y-099M-32Y-3M-5Y-0B	PCYR/LR-149	T	5MS
3	HD2281/TRAP#1/3/KAUZ*2/TRAP//KAUZ CG50-099Y-099M-22Y-2M-5Y-0B	PCYR/LR-185	TR	2MR
4	PVN/PBW65/3/KAUZ*2/TRAP/KAUZ CG74-099Y-099M-20Y-3M-4Y-0B	PCYR/LR-307	TR	2MR
5	TRAP#1/YACO/3/KAUZ*2/TRAP//KAUZ CG96-099Y-099M-39Y-3M-1Y-0B	PCYR/LR-421	TR	10MS
6	TINAMOU CM81812-12Y-06PZ-5Y-5M-0Y-3AL-0Y-8SJ-0Y	9HRWSN-24	5MS	0
7	MILAN/SHA7 CM97550-0M-2Y-030H-3Y-3Y-0Y-1M-010Y- 0FU...	9HRWSN-71	TMR	2MR
8	NG8319//SHA4/LIRA CMBW90M2302-6M-010M-010Y-015M-6Y-0M	9HRWSN-98	TMR	TMR
9	THB/CEP7780//SHA4/LIRA CMBW90M2456-9M-01OM-010Y-015M-10Y-0M	9HRWSN-102	5MR	0
10	DRL9127 CM104628-0M-17U-51Y-3U-0U	9HRWSN-132	10MR	TMR

SPATIAL TOOLS FOR WHEAT RESEARCH IN EASTERN AND SOUTHERN AFRICA

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ABSTRACT

The evaluation of spatial variation in environment is as important for wheat research and extension as for any other agricultural discipline. In the past, access to spatial information tools or spatial data sets has been limiting – largely due to reasons of cost and lack of expertise. As a result, geographical information systems (GIS) have not achieved the expected impact. This paper describes a new generation of spatial decision support tools, coupled to spatial data sets, that have been developed by the Characterization Assessment Applications Group (CAAG) at Blackland Research and Extension Center, Temple, Texas and the Natural Resources Group, CIMMYT, Mexico. These tools, namely the Africa Country Almanac and the Africa Maize Research Atlas, aim to make geography both practical and accessible to researchers at all levels. Various examples are described for applications of these tools to wheat-related research within sub-Saharan African. In Ethiopia, the Africa Country Almanac was used to characterize potential new production areas for wheat, based on agro-climatological parameters. This study had several outputs: a refinement of the current distribution of wheat production areas; identification of possible priorities for breeding programs to permit expansion into new areas; and an assessment of the representativeness of existing wheat research stations. At the regional level, the Africa Maize Research Atlas permitted the identification of potential areas for the transfer of materials, technologies, or information from an existing important wheat research station. The tools described represent entry-level GIS systems that permit non-GIS experts to analyze and interpret spatial data. They are also intended to improve spatial awareness amongst researchers, permitting more efficient use of higher level GIS resources.

INTRODUCTION

Geographical information systems (GIS) – that is computerized systems for displaying, analyzing and managing spatial data – offer great potential to improve resource efficiency within agriculture. Spatial variation in environment is as important to wheat research and extension as for any other agricultural discipline. Despite this importance, widespread use of spatial tools and data sets amongst wheat researchers is limited. Factors that have historically restricted the application of GIS include: the high cost of computer hardware and software, limited availability of digital spatial data, and the need for highly trained personnel to operate the GIS. Advances in computer hardware and software technology have permitted the development of accessible, user-friendly spatial decision support tools that aim to minimize

these barriers to the effective use of GIS. This paper describes two user-friendly spatial decision support tools that have been developed specifically to assist researchers within the sub-Saharan Africa region.

Collaboration between CIMMYT's Natural Resources Group and the Characterization, Assessment and Applications Group (CAAG) at the Blackland Research and Extension Center (Temple, Texas) has resulted in advanced spatial tools being developed, and made accessible, to researchers in the African region. The first of these tools, namely the Africa Country Almanac (Corbett *et al.*, 1999), represents one of the most advanced stand-alone spatial decision support tools available in the world. The second tool, the Africa Maize Research Atlas (Hodson *et al.*, 1999; 2000), relies on freely available but commercially produced software (ArcExplorer, from Environmental Systems Research Institute, Inc.) to provide access to digital spatial data. A key concept behind both the Africa Country Almanac and the Africa Maize Research Atlas is that they should represent much more than simple software packages. In this context, both systems come pre-loaded with data sets that are targeted particularly to the needs of researchers in agriculture and natural resource management.

Accessibility is a key factor in the successful adoption of any new technology. A considerable amount of effort has been made to make the spatial tools described here as accessible as possible to researchers and decision-makers who are not GIS-experts. Simple intuitive user interfaces, incorporating a familiar "Microsoft Windows point and click approach", have been utilized (Fig. 1) with the aim of making these systems as accessible as spreadsheets. Experience has shown that even with a minimal amount of training – in the order of two days – complete novices to the area of GIS can grasp the fundamentals of these systems and start applying them. Prohibitive costs are another barrier to widespread accessibility, but the tools described here are currently being made available at minimum cost to *bona fida* researchers for non-profit uses.

As for any technology, unless practical applications are found, a GIS tool will be of limited value. The GIS tools described in this paper are no exception. Several real world examples of the application of these systems to agricultural problems, particularly related to wheat systems, are described. These include the investigation of potential areas for the expansion of wheat production within Ethiopia, facilitating the transfer and exchange of material, technology, and/or information from existing wheat research stations, and assisting in the efficient use of resources through effective targeting.

The tools described here represent "entry-level" GIS applications, and as such have an important role to play in GIS capacity building or raising spatial awareness. Many institutions now have access to advanced GIS systems that are managed by GIS specialists. However, for a GIS laboratory to provide effective support, it must have access to collaborators who are aware of the potential applications of GIS to their work. In addition, having simple low-cost systems through which the outputs of advanced spatial analysis can be widely distributed is also vital. "Entry-level" applications, such as the Africa Country Almanac and the Africa Maize Research Atlas, therefore, have an additional role to play in awareness building that goes beyond being gateways to spatial information.

DESCRIPTION OF THE TOOLS

Africa Country Almanac

The Africa Country Almanac represents one of the most advanced examples of a new generation of spatial decision support tools. It has been developed by the Characterization, Assessment and Applications Group (CAAG) at the Blackland Research and Extension Center, Temple, Texas (part of the Texas A&M University System) in collaboration with the Natural Resources Group at CIMMYT. The Almanac is a stand-alone CD-ROM-based spatial decision support tool that provides decision-makers with an integrated set of spatial tools, data, and documents for a particular geographical region.

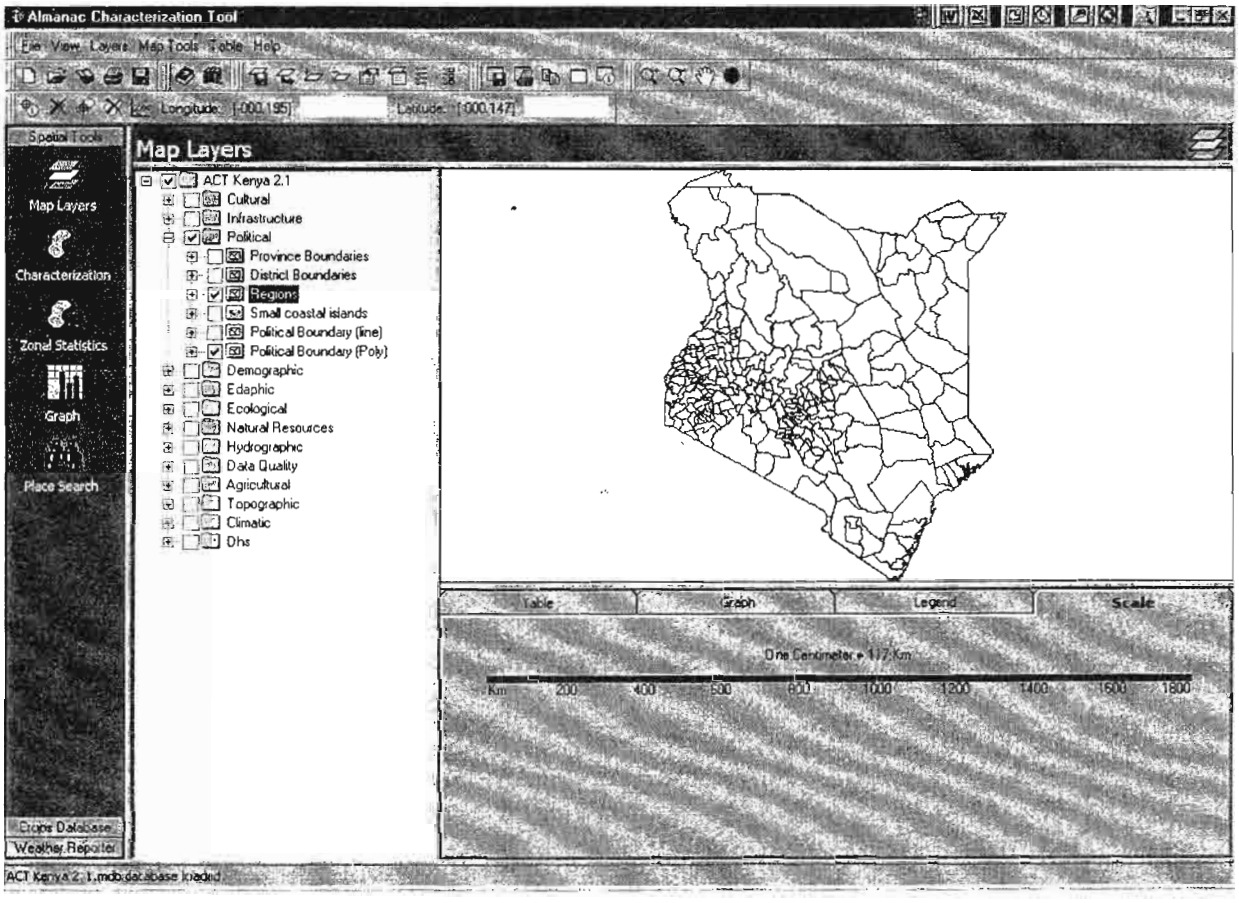

Figure 1. Africa Country Almanac Graphic User Interface.

The software development team, at the Blackland Research and Extension Center, built the Almanac using a combination of Map Objects (ESRI) and Visual Basic (Microsoft). This permits a wide range of functionality and flexibility to be incorporated into the Almanac, giving users a tremendously powerful but simple spatial decision support tool. The Almanac has been designed to be essentially an open system, and for this reason standard file formats have been used throughout. All geographical data are stored in ESRI shapefile format (probably the most common GIS file format), all databases are in Microsoft Access format (a widely used database file format), and all documents are in PDF format. This use of common formats greatly facilitates the exchange of images, graphs, and tables between the Almanac

and external software. It also makes the importation of additional data by the user relatively simple.

The main areas of functionality that have been built into the Almanac include:

Spatial Data Display

A map can be created from any spatial data within the Almanac. The system is extremely flexible in terms of how data are displayed. Users may select colors, line styles, and fill patterns to create a fully customized map. There is no limit to how many different data layers can be displayed so it is possible to visually explore spatial interactions between different data sets. Any map created in the Almanac is easily exported into external software packages, including word processing or imaging software, for use in a report or presentation.

Spatial Data Query

As the Almanac is a true GIS and not merely an image processor, complete attribute databases are linked to the data themes. This means that any existing data for a point or polygon can be retrieved or queried. This information can be displayed in tabular or graph format and exported into external software packages.

Characterization

Characterization is a core function of the Almanac. It can be used to describe areas based upon their biophysical, social, and economic characteristics, or to search for areas that fall within a predefined set of parameters. The Almanac offers two mechanisms by which to perform a characterization: Zone Mapping and Site Comparison.

Zone Mapping permits the creation of user-defined agro-ecological zones. The function is extremely flexible and essentially any spatial data set within an Almanac database can be used. A typical example of usage would be to find the zone within a particular country that is defined by a specific temperature and precipitation range within a certain elevation range.

Site Comparison allows the identification of areas that are similar to defined characteristics at a particular site. The criteria for what constitutes "similar" are user-defined and often represent a percentage variance. A typical example of usage would be to find the areas that are within +/- 10% of the annual precipitation value at a specified experimental station. This function is particularly suited to the targeting of new germplasm, technologies or information.

Graph

The visualization and presentation of spatial trends is vital for both understanding and communication. Therefore, the Almanac incorporates a very powerful graphing function. A wide range of graph types and styles are available, allowing users to fully customize the way data are displayed. Any graphs that are created in the Almanac can be exported for use in external software packages.

Additional Modules

Due to the underlying object-orientated programming used to construct the Almanac, the addition of extra functionality in modular form is possible. Currently, the Almanac contains two such additional modules that expand the basic functionality.

(i) Database Query

The Crops Database module incorporates powerful database query tools into the Almanac. These facilitate the rapid and easy retrieval of information from Microsoft Access databases. As an example, all of the CIMMYT elite maize variety trial data for Africa have been incorporated into the Almanac, and these data may be queried in several different ways.

(ii) Access to Meteorological Station Data

The Weather Reporter module permits access to daily meteorological station data. As an example, all of the data from World Meteorological Organization (WMO) stations throughout Africa have been incorporated into the Almanac. For a particular station, and any specified time period, precipitation and temperature data can be accessed in graphical or tabular format. The Weather Reporter is a useful tool with which to assess climate variability within different regions.

Africa Maize Research Atlas/East and Central Africa Maize Research Atlas

The Africa Maize Research Atlases, developed by the Natural Resources Group and the Maize Program at CIMMYT, represent digital atlases of spatial data complete with a simple GIS data exploration tool. The original Atlas covered the whole of sub-Saharan Africa (everything south of 15° N latitude), including a special focus on the SADC region of southern Africa. The same concept was used to produce the East and Central Africa version, but this version is focused on nine countries within the east and central Africa region.

The GIS data exploration tool incorporated into the Atlases is ArcExplorer. This software was developed by ESRI, but is freely available over the internet [www.esri.com] with no restrictions on distribution. These factors, coupled with functionality and ease of use, made ArcExplorer an ideal tool to incorporate into these entry-level GIS packages. The use of ArcExplorer permits the inclusion of ready-made digital maps, termed "projects", which allow users to view important data sets in a clear and meaningful way. Numerous examples of these "projects" are included, which can be used in either a stand-alone manner or as the starting point for further investigation.

The overall aim of these packages was to make as much useful spatial information as possible available to researchers in an accessible form. The data content has focused on themes relevant to agriculture or natural resources management, so information on climate, soils, elevation, land use, and population have been included. Although both products have been named Maize Research Atlases, this is something of a misnomer as in fact they represent very generic tools aimed at fostering a better understanding of environments (i.e., the naming is more closely linked to resourcing than functionality). Climate similarity maps for important maize and wheat research stations throughout sub-Saharan Africa are a major component of the Atlases (see Fig. 6 for an example). Over one hundred research stations have been included. The similarity maps identify potential areas where efficient transfer of materials,

technology and information within the region may be possible. These maps are particularly suited for use within projects that have a regional focus.

Overall, the Atlases aim to provide a wealth of easily accessible spatial data compiled within a single source. This should enable researchers to explore and characterize the environments in which they are working in a much simpler and faster way than was previously possible.

APPLICATIONS OF THE SPATIAL TOOLS

Numerous applications of the spatial tools outlined in this paper already exist, but the focus in this section will be on those related to areas of wheat research. In each of the examples described below, it should be stressed that researcher input was by far the most important factor. It is the wheat researcher who knows the climatic parameters that make the most sense for a particular region, not the GIS expert!

Example One: Characterization of Potential Wheat Expansion Zones in Ethiopia

A detailed account of this work can be found in White *et al.* (in preparation), and only a brief overview of the study and the major findings will be presented here.

This study was conducted almost exclusively by utilizing the tools and data sets contained within the Ethiopian Country Almanac. The overall objective was to respond to a request from the Directorate of EARO to explore the possibilities for expanding the wheat production zone within Ethiopia into new areas. The underlying rationale behind this is that Ethiopia falls short of being self-sufficient in wheat production, and is currently a net importer of wheat grain. Although there is significant scope for yield improvement within traditional wheat production areas, interest has been expressed in the possibility of expanding wheat production into non-traditional areas. Obviously, from a planning and resource mobilization viewpoint, such a strategy raises numerous questions. If potential new areas do exist, then what are their characteristics? Where are they located? What problems are likely to be encountered? What are the likely breeding strategies that will have to be employed? What are the likely gains in area? The tools and data offered by the Africa Country Almanac, although not a "cure-all", can greatly assist in this decision-making process.

Climatic characterization of the existing wheat zone indicated that precipitation and minimum temperature during the wettest quarter (i.e., the three consecutive wettest months) were the key determinants of potential wheat areas. Using a lower limit of 350 mm for precipitation and a minimum temperature range between 6 and 11 °C, coupled to a season length of no more than 9 months, resulted in a distribution that matched closely published sources of traditional wheat areas (as depicted in Belay *et al.*, 1999) and local expert knowledge (Fig. 2). Further independent confirmation of the accuracy of this zone was obtained from the distribution of bread wheat germplasm collection sites in Ethiopia derived from the USDA GRIN online database (USDA-ARS-NGRP, 2000) – nearly all locations fell within this derived zone.

Having determined the climatic factors that accurately described the current wheat production areas of Ethiopia, it was then possible to explore options for potential areas for expansion. Considering that water deficits and warm night temperatures appeared to be key factors delimiting bread wheat production in Ethiopia, potential new areas for bread wheat production were identified by assuming that technologies could be developed to allow wheat

to be grown in drier or warmer environments. Lowering the minimum rainfall limit to 300 mm within the wettest quarter resulted in a very small expansion to the wheat production zone (Fig. 3). Conversely, raising the minimum temperature limit by 2 °C resulted in a virtual doubling of the potential wheat area on the periphery of the highlands (Fig. 4). These "new" areas fall roughly in the 1900-2100 m altitudinal range – lower than the traditional wheat areas.

Figure 2. Current major wheat production area in Ethiopia based on the map depicted in Belay *et al.* (1999), and predicted wheat distribution area based on climatic factors (i.e., wettest quarter precipitation > 350 mm, minimum temperature from 6-11 °C, from White *et al.* (in preparation)).

These results may seem counter-intuitive given the popular conception of Ethiopia as a drought-prone, arid environment. The principal explanation is that in terms of wheat cropping – and ignoring year to year variation – the highlands of Ethiopia, to which the wheat crop is so well-adapted, represent a relatively humid environment. Precipitation during the wettest three months is usually well in excess of Potential Evapotranspiration.

It is important to note that this study relied solely on climatic variables. Other factors (e.g., soils, topography, socio-economic, and existing crop distribution) will further restrict the area where wheat can be grown. However, the results do provide useful input to the decision-making process. If a large expansion in the geographical area of wheat production is desired,

then focussing breeding efforts on developing wheat lines with improved tolerance of heat and/or the diseases associated with warmer conditions (e.g., *Helminthosporium sativum*) appears to make more sense than targeting the development of drought tolerant germplasm.

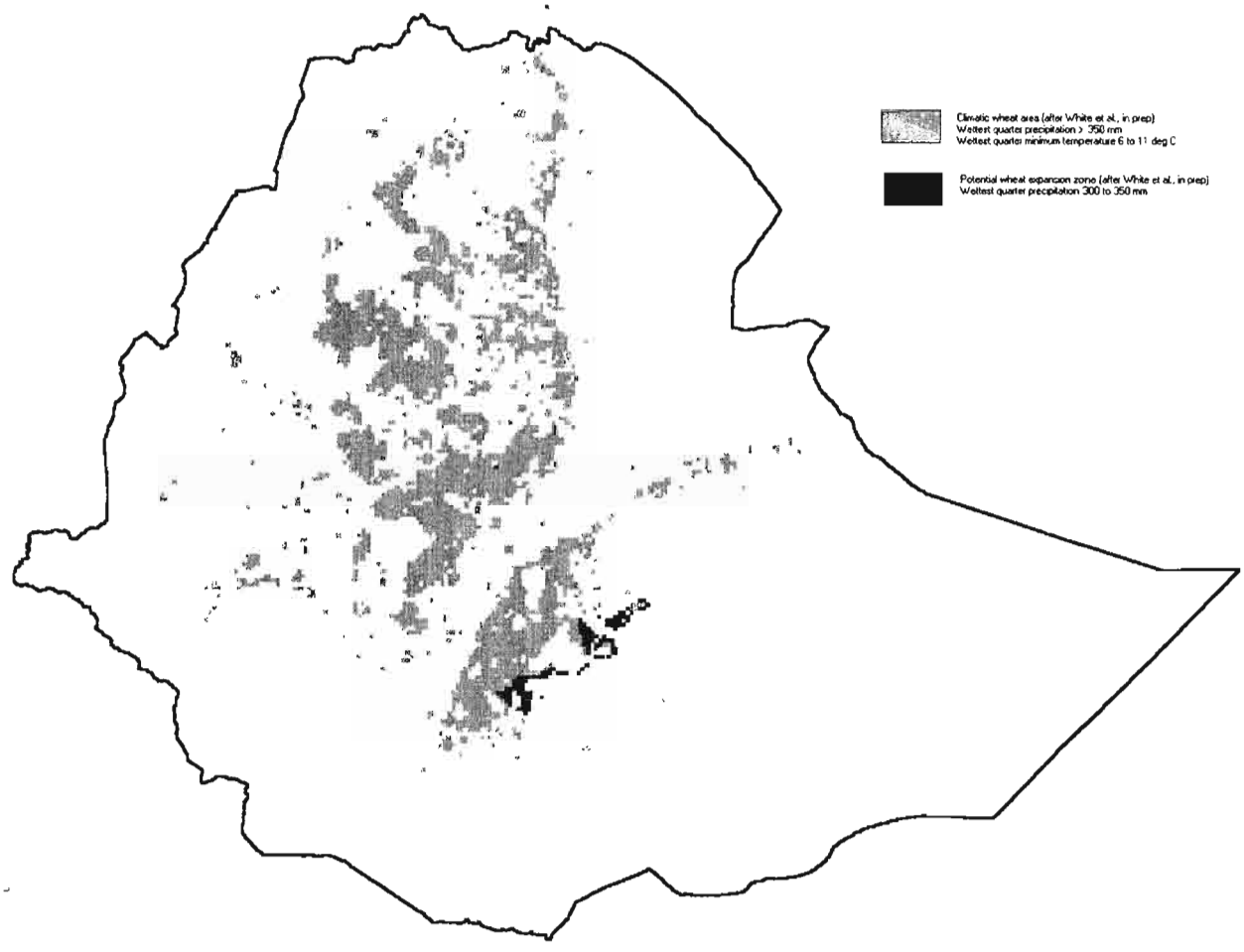

Figure 3. Potential wheat expansion zone resulting from lowering the wettest quarter precipitation value to 300 mm.

Example Two: How Representative are Existing Experimental Stations of the Current Ethiopian Wheat Production Areas?

This was another facet examined by the White *et al.* (in preparation) study described above in example one. Climate similarity maps were generated for eight key wheat research sites used by the National Wheat Research Program of Ethiopia. To generate these maps, climatic data from the experimental sites were used as inputs and zones were generated to represent a range based on the site values (+/- 50 mm for precipitation and evaporation, +/- 1 °C for maximum and minimum temperature). These similarity zones were then compared to the wheat production area. Once again, the Ethiopia Country Almanac was used to carry out this work.

The results showed that existing research centers represent most of the Ethiopian wheat production zone and exhibited little overlap between stations, i.e., no two stations covered the

same specific climatic conditions (Fig. 5). The implication of these results was that the existing wheat research stations in Ethiopia are well located – being both representative and exhibiting little duplication of environments.

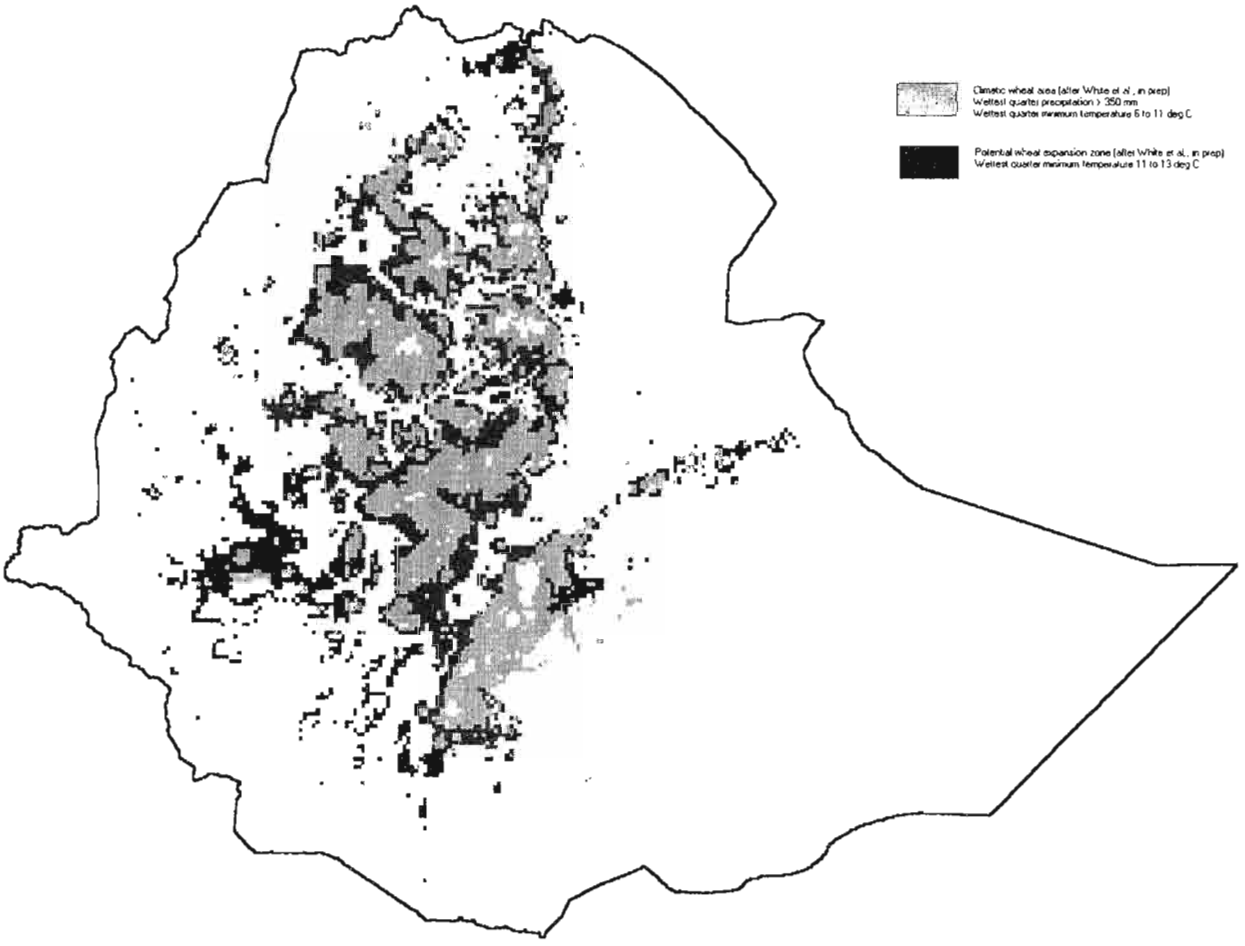

Figure 4. Potential wheat expansion zone resulting from raising the upper limit of minimum temperature during the wettest quarter to 13 °C.

Example Three: Identification of Potential Transfer Zones for Technology from the Kulumsa Experimental Station, Ethiopia

The Kulumsa research station is widely recognized as a center of excellence for bread wheat research within the region. This station already actively collaborates in regional networks, but the question was asked: Are there other areas where the transfer of materials, technologies or information to and from Kulumsa may be appropriate? The climate similarity maps contained within the Africa Maize Research Atlas were used to address this question at the regional level.

The results highlighted the climatic similarity of Kulumsa to most of the major wheat producing regions in eastern Africa (Fig. 6), and support the pivotal role in regional networks that Kulumsa is providing. One surprise finding was that a significant area in eastern South Africa exhibited climatic similarity to Kulumsa, yet this was not a wheat producing region. This prompted an investigation into what additional factors were involved in this particular

region. It was discovered that several factors were involved, including difficult terrain, wheat not being a crop of choice for traditional small-holders, and high levels of commercial production in south-western areas. This example highlights the fact that factors, including socio-economic issues, must also be considered when examining crop distributions.

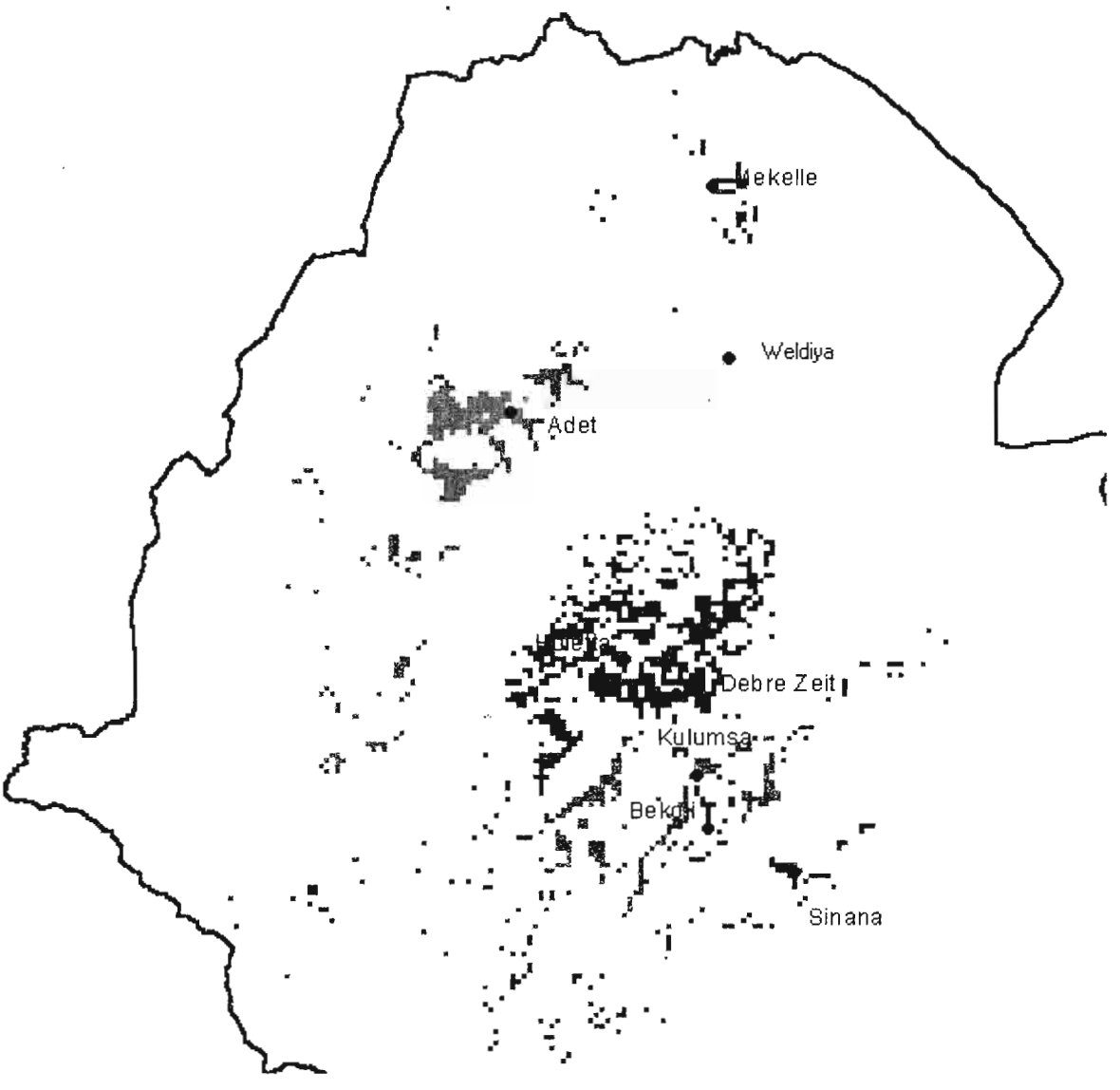

Figure 5. Climatic similarity zones for existing wheat research centers in Ethiopia.

Example Four: Effective Targeting of Marketing Activities by a Private Seed Company in Zimbabwe

The final example of an application of the spatial tools is not a wheat example, but the principle it outlines is certainly applicable to wheat.

SeedCo, one of the largest private seed companies in Zimbabwe, applied the tools and data sets of the Zimbabwe version of the Africa Country Almanac in order to target marketing activities for a newly released groundnut variety. By generating similarity zones to testing locations, SeedCo was able to effectively determine the adaptation zones within Zimbabwe for the new variety. Marketing activities were then focused on these regions. Utilization of

such a strategy obviously makes sense in economic terms, representing significant cost savings for the company, and more effective marketing is a likely outcome.

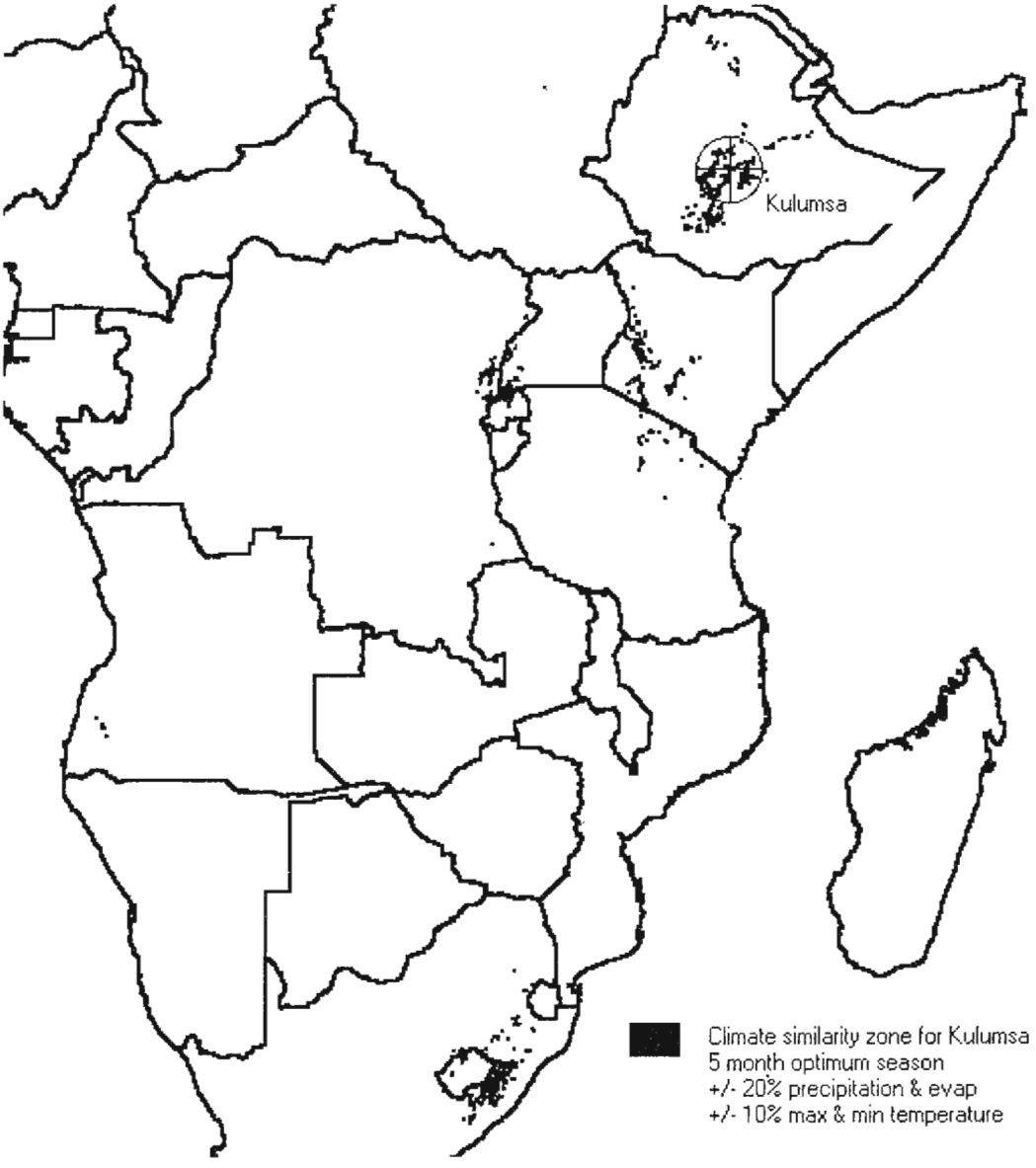

Figure 6. Climate similarity map for the Kulumsa Reseach Center, Ethiopia.

RAISING AWARENESS OF SPATIAL TOOLS

The tools described in this paper do not represent, and are not intended as substitutes for, complete commercial GIS systems. Instead, they are entry-level packages that provide a range of tools and spatial data sets. In addition to the stand-alone functionality these packages exhibit, they also have a role to play in raising the spatial awareness of agricultural researchers. The change from a simple paper map to an interactive digital spatial database is a major advance, and opens up many new possibilities for analyses that in the past were practically impossible. These entry-level packages help bridge the technology gap and provide stepping-stones to more advanced GIS capabilities. They have an important educational role to play in the more efficient use of advanced GIS laboratories. For a GIS

laboratory to provide effective support, it must have access to collaborators who are aware of the potential application of GIS to their work.

Examples of the types of more advanced analyses that have been undertaken by the GIS laboratory at CIMMYT have included:

- Modeling the risk of drought within the SADC region, both spatially and quantitatively, during different maize development stages.
- Selecting survey locations — based on homogeneous agro-ecological zones (generated by cluster analysis) with random points assigned within these zones. Such an approach resulted in truly representative survey locations, making survey results valid for larger defined regions. Due to the ability of GIS to handle exact map projections and scales, it was simple to transfer locations from "screen to field" by printing onto commercial topographic maps that could then be used in the field (Hodson *et al.*, in preparation).
- Hydrological modeling of a new experimental station to assist the planning and design process.

None of these applications would have been possible without collaborators who had some awareness of what a GIS could do. In all cases, it has been possible to incorporate the results of these more advanced analyses into simple stand-alone systems as described in this paper. The results are then available and can be distributed amongst a wide range of researchers.

CONCLUSION

The spatial tools described in this paper represent a new generation of spatial decision support systems. The old barriers to effective use of GIS by agricultural scientists, namely cost, complexity and data availability, are now being broken down with tools such as the Africa Country Almanac and the Africa Maize Research Atlas. These tools provide researchers with powerful, yet simple to use, spatial tools and data sets, making access to digital spatial data relatively simple.

Several examples are described of how these tools have already been applied to address wheat-related research questions within eastern and southern Africa. These examples illustrate how a better understanding and characterization of the geographic environment can lead to improved input into decision-making processes, and, ultimately, to more efficient use of resources.

The importance of these tools to develop an improved spatial awareness amongst researchers was also highlighted. The stand-alone spatial tools described in this paper, although very powerful, will not permit every possible type of spatial analysis. However, once researchers have been exposed to spatial data and tools, they should then be in a much better position to exploit more advanced GIS services. The tools described in this paper also provide ideal vehicles by which the results of complex analyses can be distributed widely amongst researchers.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Environmental Systems Research Institute, Inc. for software support.

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Questions and Answers:

Mamoun I. Dawelbeit: 1) Does the information cover all the countries in the Region? 2) What size of computer is required to run this software?

Answer: 1) The Country Almanac covers Ethiopia, Kenya, Tanzania, Uganda, Zambia, and Zimbabwe. The Africa Maize Research Atlas covers the whole region from Ethiopia extending South. The East Africa Maize Atlas covers: Sudan, Ethiopia, Kenya, D.R. Congo, Rwanda, Burundi, Tanzania and Madagascar.

2) Any machine that runs Windows 95, 98 or NT will run either the Almanac or the Atlas. Recommend Pentium 32 MB RAM as minimum – faster is better for large countries like Ethiopia.

RESPONSE OF SOME DURUM WHEAT LANDRACES TO NITROGEN APPLICATION ON ETHIOPIAN VERTISOLS

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ABSTRACT

Landrace durum wheat constitutes one of the major cereals grown on Vertisols in the central highlands of Ethiopia. Their productivity is limited, among other factors, by low soil fertility, including nitrogen deficiency. Consequently, inorganic N fertilization is recommended at a rate of 60 to 90 kg N/ha for improved durum wheat varieties under different cropping systems. However, little information is available on the differential response of landraces to applied N. This led to the initiation of a field experiment at two representative Vertisol locations, Akaki and Cheffe Donsa, in the central highlands. The experiment was conducted for three years (1993-1995) on three promising durum land race genotypes (A2-138, E1-9 and B1-9 for Akaki, and A2-187 and B1-9 for Cheffe Donsa). Kilinto and DZ04-118 for Akaki, and DZ0320 and DZ04-118 for Cheffe Donsa were used as local and standard checks, respectively. Six levels of N (0, 15, 30, 60, 90 and 115 kg/ha) were used in factorial combination with the landraces and checks. The results showed that the effects of N rate were significant on both grain and straw yields at both locations. Differences among the landraces were significant for both grain and straw yields at Akaki, but only for grain yield at Cheffe Donsa. The interaction effects of landraces by N rates were significant in two out of the three years on grain and only one out of the three years on straw yield at both locations. Generally, grain and straw yields increased with N level while the biological optimum for each was different. The landraces tended to have an advantage over the local and the standard checks in their specific areas of adaptation, particularly with respect to straw yields. Hence, emphasis should be directed towards determining the economic optimum rate of N application on Vertisols for optimum wheat grain and straw production.

INTRODUCTION

On Vertisols of the central highlands, a mixture of several tetraploid wheats which are suitable for making unleavened bread and pasta products are predominant. They cover about 60% of the total area devoted to wheat production (Hailu, 1991) with mean GYs estimated at around 1 t ha^{-1}, and hence contribute roughly 10% to the annual cereal production in Ethiopia (Tesfaye and Getachew, 1991). In recent years, study for the identification of genotypes with good yield is underway. Their release at their respective original collection sites is hoped to improve the current poor yields.

With fertilizers becoming important inputs to maximize crop yield and nitrogen fertilizer being determinant in durum wheat, several N fertilizer trials have been undertaken to

determine the optimum levels for economically profitable yields (DZARC, 1988; 1989). Results indicate that N rates had significant effect on yield up to 230 kg ha^{-1} (Samuel, 1981; Desta, 1988; Miressa, 1992; Lemma *et al.*, 1992). On the whole, the new high yielding cultivars have a higher nutrient requirement because of their increased yield potential.

In spite of this, there is as yet little information on the differential fertilizer responses of high yielding durum wheat lines selected from the Ethiopian landrace population to increasing rates of N on Vertisols in the central highlands. Therefore, this study was launched to partly supply this information.

MATERIALS AND METHODS

A factorial experiment in a randomized complete block design with three replications was conducted at Akaki and Cheffe Donsa on pellic Vertisols for three main cropping seasons (1993/94-1995/96). The experiment was conducted on flat seedbed of 4 by 4 m using three promising landrace durum wheat genotypes selected from their respective location. Consequently, A2-138, E1-9 and B1-9 were selected from Akaki, with Kilinto and DZ04-118 as the local and standard checks, respectively. At Cheffe Donsa, A2-187, A1-138 and B1-9 were the landraces while DZ-320 and DZ04-118, in that order, were the local and standard checks. These were broadcast at seeding rates recommended for each landrace variety. Nitrogen levels were 0, 23, 46, 69, 92 and 115 kg N ha^{-1} as urea applied in split; half at sowing and the other half at full tillering. Fifteen kg P ha^{-1} was uniformly broadcast and incorporated into the soil at sowing. Grain and straw yield responses were recorded.

RESULTS AND DISCUSSION

Akaki: There were significant differences in both grain and straw yields throughout the three years due to varieties as well as nitrogen application rates (Tables 1 and 2). The interaction effect between the varieties and N rates, however, was significant in two and one out of the three years for grain and SY, respectively. The results conform to the findings of Miressa *et al.* (1992) who reported varietal effect on nitrogen uptake in durum wheat. During the first year (1993/94), E1-9 gave the highest GY 3504 kg/ha followed by B1-9 and A2-138, respectively, while the standard check DZ04-118 gave the least GY (2993 kg/ha). For reasons not clear, the highest GY (3662 kg/ha) due to 92 kg N/ha was not significantly different from 3318 kg/ha obtained with the application of 23 kg N/ha. Similarly, the GY obtained with no N fertilizer application was not significantly different from the amount obtained due to 46 kg N/ha. Further application of N above 92 kg N/ha resulted in slightly reduced GY. Similar to the GY, E1-9 gave the highest SY followed by B1-9 and A2-138. The highest mean SY (5350 kg/ha) was obtained with the application of the highest N (115 kg/ha) followed by 5338 and 5102 kg/ha obtained with 69 and 92 kg N/ha, respectively, against the least which was obtained from the no N fertilizer treatment. As opposed to the GY, the highest N rate did not result in reduced SY. Generally, there was a consistent increase in SY with increase in N application rates as expected due to the positive role of N on vegetative growth.

In 1994/95, unlike the previous year, the interaction effect of the varieties and the nitrogen application rates was significant for both grain and SY. DZ04-118 gave the highest grain and SY while A2-138 gave the least. The highest GY of 2386 kg/ha and SY of 3207 kg/ha were obtained with N application rate of 92 kg N/ha, but the GY was not statistically greater than

the yields obtained due to 69 kg N/ha. There was a general grain and SY increase with increase in N application rates up to 92 kg N/ha for all the varieties, confirming the previous findings (DZARC, 1988, 1990; Miressa *et al.*, 1992). However, the yield of A2-138 increased only up to the maximum of 69 kg N/ha and decreased with further increase in N rates. This shows the difference in N requirement of the varieties under the same environmental conditions (Miressa *et al.*, 1992).

During the last year (1995/96), the effects of the landraces and the nitrogen rates in terms of grain and SY and their interaction on GY were significant. Kilinto, as in the first year, gave the highest grain and SY but followed by B1-9 for grain and DZ04-118 for SY. There was grain and SY increase up to the maximum N application rate except a slight decrease in GY of A2-138 at the highest rate. Significantly highest grain and SY (2468 and 3403kg/ha, respectively) were obtained with the application of 115 kg N/ha. All the landraces had a similar pattern of response to increasing levels of N.

During the first two years (1993/94 and 1994/95), the landraces, E1-9 and B1-9, showed better performance in terms of SY compared to the local check Kilinto and the other landrace (A2-138). On the other hand, Kilintó has shown best performance in terms of GY during the first and the last years. This performance is quite logical since Kilinto is the variety released for the area. This could also be due to the highest seasonal rainfall of 1993/94 and 1995/96 (Table 5) with its better distribution as compared to the other year. This situation particularly favored the local check Kilinto, which responded best during the year. Consequently, since yield is the result of multiple variables, it can be inferred that it is not only N fertilization and variety that determine crop yield, but also the prevailing weather, soil and other environmental conditions. Crops therefore respond to N fertilization best under favorable environments.

Cheffe Donsa: The effect of N application rates was significant on GY (Table 3) and SY (Table 4) throughout the period of the three years. However, the difference between the landrace varieties was significant only in GY and not in SY. The interaction effect between the N application rates and the landrace varieties was significant in 1994/95 for grain and SY but only for GY in 1995/96.

In 1993/94, A1-138 gave the highest GY (2337 kg/ha) followed by DZ04-118 and B1-9, respectively, while DZ-320 gave the least. In Table 3 it is shown that there was no significant GY increase beyond 69 kg N/ha application and the yield started to slightly drop beyond 92kg N/ha. However, the SY increased from 2010 kg/ha to 3293 kg/ha in response to the increase of N fertilization from 0 to 115 kg N/ha even though there was no significant difference between the last three higher rates in terms of both grain and SY.

In the second year, there was a significant difference in GY due to the landraces, nitrogen rates and their interaction while the effect of the landraces on SY was not significant. B1-9 gave the highest GY followed by DZ 04-118 and A1-187, respectively. There was a steady increase in GY from 783 kg/ha to 2113 kg/ha in response to the corresponding increase of N from 0 to 115 kg. Similarly, the SY increase was from 1140 to 2372 kg/ha. This confirms the previous findings Samuel (1981) who reported grain and SY increases of durum wheat grown on Vertisols. The difference in GY due to the varieties, nitrogen application rates and their interaction was statistically significant in 1995/96. In Table 3 it is shown that B1-9 gave the highest GY followed by A1-138 and A2-187, respectively.

There was a general increase in GY with an increase in N application rates up to the highest rate for all the varieties except for DZ 04-118, which decreased beyond 92 kg N/ha application. The landraces did not significantly differ in GY among themselves, but were significantly higher than the local as well as the standard checks, which were in turn not statistically different from each other. B1-9 gave the highest GY (2350 kg/ha) while DZ 04-118 gave the lowest (2003 kg/ha).

In contrast to the GY, there was no difference in SY among the varieties and their interaction with N rates. However, there was a significant difference between the SY due to increasing N application rates. The highest SY (4455 kg/ha) was obtained with application of 115 kg N/ha while the lowest was with no N fertilization.

SUMMARY AND CONCLUSIONS

The landrace varieties responded to N application rates differently at both locations. Considering both grain and SY, they generally increased in response to N application rates of 69 and 115 kg N/ha at Akaki (Fig. 1) and Cheffe Donsa, respectively. Generally, the landraces tended to have advantage over the local as well as the standard checks in their specific area of adaptation. This is particularly true with respect to SY.

At Akaki, the landrace variety A2-138 gave its highest possible grain and SY with N application rate of 69 kg/ha. Therefore, farmers of the locality may not need to apply beyond this rate. For the other varieties, generally the GY increase was up 92 kg N/ha while the SY increased with further increase of N rate. Hence, when GY is the major economic interest, 92 kg N/ha may be optimum provided it is economically paying. In general, reference should be made to the performance of each variety under specific environmental conditions.

At Cheffe Donsa, both grain and SY increased significantly up to the maximum N fertilization rate (115 kg/ha). This is particularly significant for the landraces. Therefore, provided it is economical, higher grain and SY can be obtained with higher N rates, regardless of the variety.

At both locations, generally the yield was low due to the prevailing heavy waterlogging as a result of the heavy rainfall and low permeability of the nearly saturated Vertisols. The use of improved drainage could increase yield by 50-100% (Abate *et al.*, 1993) under such conditions. Hence, N fertilization should be combined with surface drainage to achieve economically and ecologically attainable yield. Since the response to N fertilization can be affected by the availability of other nutrients such as P, factorial experiments should be carried out to fine-tune the recommendation.

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Questions and Answers:

Wolfgang H. Pfeiffer: For many production constraints, we have genetic solutions and agronomic solutions. You mentioned waterlogging as a major problem. Since many traits have to be considered in plant improvement, will it be possible to attack the problem through agronomic measures?

Answer: There are three types of waterlogging problems associated with Ethiopian highland Vertisols. Out of these, water ponding on the surface can be easily managed by agronomic measures. The other two, high water label and rise in ground water level need more machinery and area-wide drainage schemes that cannot be handled by individual farmers.

Temam Hussien: You said that as the materials are planted in high altitude areas, stem rust and leaf rust were not a problem. How about yellow rust?

Answer: The disease is there but not at an intensity that limits the yield.

Table 1. Grain yield of landrace durum wheat as affected by N rates (Akaki).

Year	Variety	Nitrogen rates (kg ha^{-1})						
		0	**23**	**46**	**69**	**92**	**115**	**Mean***
1993/94	A2-138	2799	2830	3173	3455	3653	3043	3159^{AB}
	E1-9	3079	3846	2948	3826	3968	3359	3504^{A}
	B1-9	2836	3510	3369	3875	3585	3637	3469^{A}
	Kilinto	3054	2817	3124	3163	2862	3506	3088^{AB}
	DZ04-118	2484	2817	3124	3163	2862	3506	2993^{B}
	Mean	**2850^{C}**	**3318^{AB}**	**3220^{BC}**	**3565^{AB}**	**3662^{A}**	**3410^{AB}**	
	C.V.(%) = 13.6; LSD(5%) (kg ha^{-1}) N = 430; V = 420; NxV = NS							
1994/95	A2-138	423	864	1979	2243	1933	1633	1512^{B}
	E1-9	894	1321	2210	2162	2472	1953	1835^{AB}
	B1-9	1003	1641	1229	2174	2189	2516	1792^{AB}
	Kilinto	636	1010	1522	1984	2715	2036	1650^{AB}
	DZ04-118	1051	1507	1631	2294	2621	2459	1927^{A}
	Mean	**801^{D}**	**1269^{C}**	**1714^{B}**	**2171^{A}**	**2386^{A}**	**2119^{A}**	
	C.V.(%) = 20.6; LSD(5%) (kg ha^{-1}) N= 367; V= 332; NxV = 611							
1995/96	A2-138	1136	1437	1702	2206	2092	2078	1775^{B}
	E1-9	1304	1691	1790	1863	2003	2165	1803^{B}
	B1-9	1314	1392	1809	2243	2096	2480	1889^{B}
	Kilinto	1289	2090	2043	2687	2805	3072	2331^{A}
	DZ04-118	1044	1545	1832	1936	2035	2545	1823^{B}
	Mean	**1217^{E}**	**1631^{D}**	**1835^{C}**	**2187^{B}**	**2206^{B}**	**2468^{A}**	
	C.V.(%) = 10; LSD(5%) (kg ha^{-1}) N = 180; V= 175; NxV = 327							

* Mean values within the same factor followed by the same letter are not statistically different at 95% confidence interval.

Table 2. SY of durum landrace varieties as affected by N (Akaki).

Year	Variety	Nitrogen rates (kg ha^{-1})						
		0	23	46	69	92	115	Mean*
1993/94	A2-138	3885	3652	4003	5434	5236	5105	4518^{AB}
	E1-9	4144	5043	4830	5619	6032	5052	5120^{A}
	B1-9	3831	5009	4409	5570	5374	6181	5062^{A}
	Kilinto	3206	3452	3537	4087	5317	4843	4074^{B}
	DZ04-118	3627	3294	4283	4800	4730	5568	4384^{AB}
	Mean	**3698^{B}**	**4090^{B}**	**4212^{B}**	**5102^{A}**	**5338^{A}**	**5350^{A}**	
	C.V.(%) = 13.63; LSD(5%) kg ha^{-1} N = 790; V= 781; NxV = NS							
1994/95	A2-138	874	1173	2657	3128	2511	2367	2118^{B}
	E1-9	1329	1827	2790	3024	3454	2677	2517^{A}
	B1-9	1589	2433	2104	3196	3367	3224	2652^{A}
	Kilinto	1031	1397	1626	2461	3211	2409	2022^{B}
	DZ04-118	1727	2019	2258	3409	3490	3838	2790^{A}
	Mean	**1308^{D}**	**1770^{C}**	**2287^{B}**	**3044^{A}**	**3044^{A}**	**2903^{A}**	
	C.V.(%) = 18.5; LSD(5%) kg ha^{-1} N = 421; V = 326; NxV = 764							
1995/96	A2-138	1811	2044	2594	3350	3056	3229	2697^{AB}
	E1-9	2104	2234	2617	2618	2998	3243	2636^{B}
	B1-9	2205	1904	2413	2979	3051	3505	2676^{AB}
	Kilinto	2009	2761	2513	3480	3195	3558	2919^{A}
	DZ04-118	1751	2270	2871	3138	3076	3381	2748^{AB}
	Mean	**1976^{D}**	**2243^{D}**	**2602^{C}**	**3113^{B}**	**3075^{B}**	**3403^{A}**	
	C.V.(%) = 10.5; LSD(5%) kg ha^{-1} N= 271; V = 267; NxV = NS							

* Mean values within the same factor followed by the same letter are not statistically different at 95% confidence interval.

Table 3. Grain yield of durum landrace varieties as affected by N (Cheffe Donsa).

Year	Variety	Nitrogen rates (kg ha^{-1}) 0	23	46	69	92	115	Mean*
1993/94	A2-187	1749	1820	1800	2182	2327	2216	2015^{B}
	A1-138	1883	2257	2039	2795	2580	2468	2337^{A}
	B1-9	1620	2168	2296	2147	2420	2590	2207^{AB}
	DZ-320	1350	1534	1209	1869	2180	2145	1714^{C}
	DZ04-118	1499	1925	2109	2487	2510	2391	2154^{B}
	Mean	**1620^{C}**	**1941^{B}**	**1890^{B}**	**2296^{A}**	**2403^{A}**	**2362^{A}**	
	C.V.(%) = 12.8; LSD(5%) (kg ha^{-1}); N = 252; V = 248; NxV = NS							
1994/95	A2-187	679	1080	1470	1603	1380	2155	1394^{A}
	A1-138	654	1285	1207	1774	2155	2360	1573^{A}
	B1-9	883	864	1310	1593	1734	1941	1386^{AB}
	DZ-320	769	1125	1136	1500	1847	1949	1388^{B}
	DZ04-118	933	1099	1257	1216	1775	2158	1406^{B}
	Mean	**783^{F}**	**1091^{E}**	**1276^{D}**	**1537^{C}**	**1778^{B}**	**2113^{A}**	
	C.V.(%) = 13.7; LSD(5%) (kg ha^{-1}); N = 242; V = 182; NxV = 535							
1995/96	A2-187	2180	1216	1795	2173	2364	3170	2206^{A}
	A1-138	2599	1478	1929	2364	2547	3109	2338^{A}
	B1-9	1847	1791	2050	2525	2867	3021	2350^{A}
	DZ-320	1234	1444	1699	2204	2558	2900	2006^{B}
	DZ04-118	1174	1505	1780	2220	2700	2637	2003^{B}
	Mean	**1806^{D}**	**1487^{B}**	**1851^{D}**	**2297^{C}**	**2674^{B}**	**2967^{A}**	
	C.V.(%) = 7.6; LSD(5%) (kg ha^{-1}); N = 167; V = 162; NxV = 774;							

* Mean values within the same factor followed by the same letter are not statistically different at 95% confidence interval.

Table 4. SY of durum wheats landrace varieties as affected by N (Cheffe Donsa).

Year	Nitrogen rates (kg ha^{-1})							
	Variety	**0**	**23**	**46**	**69**	**92**	**115**	**Mean***
1993/94	A2-187	2140	2068	2510	3077	3414	3154	2773
	A1-138	2191	2558	2406	3316	3346	3028	2808
	B1-9	1899	2461	2890	3112	2951	3521	2806
	DZ-320	1983	2170	1939	1986	3190	3411	2447
	DZ04-118	1834	1964	2520	2883	3230	3349	2630
	Mean	**2010^{C}**	**2244^{C}**	**2453^{BC}**	**2875^{AB}**	**3226^{A}**	**3293^{A}**	
	C.V.(%) = 21.1; LSD(5%) (kg ha^{-1}); N =532; V = NS; NxV = NS							
1994/95	A2-187	1173	1328	1678	2101	1509	2476	1711
	A1-138	1003	1576	1570	2103	2475	2659	1897
	B1-9	1154	1136	1656	1926	2155	2318	1724
	DZ-320	1083	1282	1530	1833	2227	2124	1680
	DZ04-118	1289	1308	1706	1562	2114	2284	1711
	Mean	**1140^{D}**	**1326^{D}**	**1628^{C}**	**1905^{B}**	**2096^{B}**	**2372^{A}**	
	C.V.(%) = 14.8; LSD(5%) (kg ha^{-1}); N = 242; V = NS; NxV = 613							
1995/96	A2-187	1559	2043	2762	3456	4153	4497	3078
	A1-138	1634	2152	2775	3414	3860	4150	2998
	B1-9	1689	2357	2876	3697	4133	4535	3214
	DZ-320	1767	2297	2597	3473	4410	4286	3138
	DZ04-118	1665	2229	2364	3409	3449	4807	2987
	Mean	**1663^{F}**	**2216^{E}**	**2675^{D}**	**3490^{C}**	**4001^{B}**	**4455^{A}**	
	C.V.(%) = 9.06; LSD(5%) (kg ha^{-1}); N = 422; V = NS; NxV = NS							

* Mean values within the same factor followed by the same letter are not statistically different at 95% confidence interval.

Table 5. Rainfall and soil characteristics of the experimental sites.

Location	Year	Rainfall (mm)		pH (H_2O)	Clay (%)	Organic Matter (%)	Total N (%)
		Seasonal*	Total				
	1993/94	704	966				
Akaki	1994/95	634	789	7.7	75	1.9	0.06
	1995/96	707	922				
	1993/94	799	988				
Cheffe Donsa	1994/95	na	na	8.1	74	2.3	0.08
	1995/96	na	na				

Seasonal refers to total rainfall received during the months from June to September.
na = data not available.

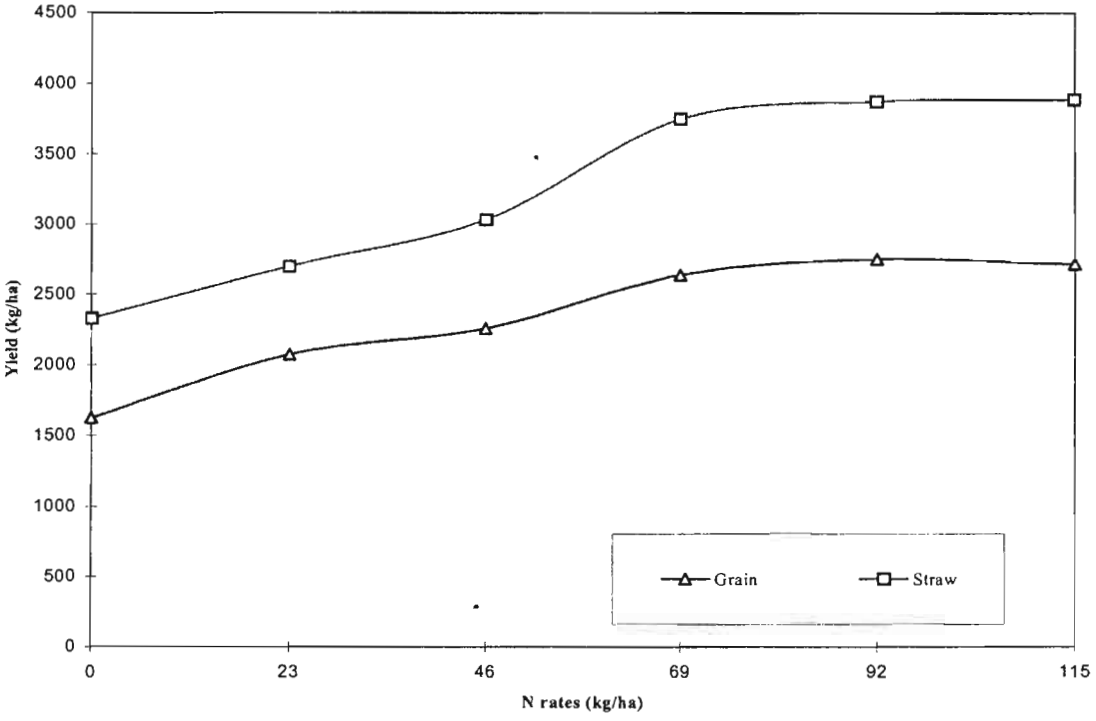

Fig. 1. Three year mean grain and straw yields of land race durum wheat varieties at Akaki as affected by N rates.

AGRONOMIC AND ECONOMIC EVALUATION OF THE ON-FARM N AND P RESPONSE OF BREAD WHEAT GROWN ON TWO CONTRASTING SOIL TYPES IN CENTRAL ETHIOPIA

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ABSTRACT

Nutrient deficiency is one of the major constraints to wheat (*Triticum* spp.) production in Ethiopia. A multi-location on-farm N and P fertilizer trial was conducted during the 1995 and 1996 cropping seasons in a poorly drained Vertisol zone, using an improved drainage technique, and in a highly-weathered reddish-brown Nitisol zone in the central highland of Ethiopia. The objectives were to determine yield and yield component response of a recently-released, high-yielding bread wheat (*T. aestivum*) cultivar to applied nitrogen (N) and phosphorus (P) rates, and to generate zone-specific, economically-optimal N and P recommendations for wheat production in central Ethiopia. The results from the combined analyses for each zone indicated a highly significant yield response to fertilizer application. Wheat grain yield responded significantly to both N and P in each soil zone, although the response to N was more pronounced. N by P interaction was non-significant for virtually all crop parameters studied in both zones. Optimum N and P_2O_5 nutrient rates were established for each zone using discrete and continuous economic analyses under three cost/price scenarios. Optimum nutrient rates were presented in a user-friendly tabular format for ease of interpretation by extension staff and policy-makers. Such a tabular format provides a dynamic template for extension staff to use when determining rates of N and P_2O_5 to recommend, facilitates interpolation of cost/price levels, and can provide insights for policy-makers when estimating the potential impact of policy interventions affecting grain and nutrient price levels.

INTRODUCTION

Wheat is a principal traditional cereal crop in the highlands of Ethiopia and is produced exclusively under rainfed conditions at altitudes ranging from 1500 to 3000 m a.s.l. (Hailu, 1991). The central highland of Ethiopia is historically an important wheat-growing region. In this region, wheat ranks second in total area coverage, production and market demand after tef (*Eragrostis tef*) (CSA, 1997a), and is produced across a range of soil conditions, particularly on well-drained highly-weathered reddish-brown soils (Nitisols) and poorly-drained heavy dark clay soils (Vertisols) (Asnakew *et al.*, 1991; Hailu, 1991). Of the total current wheat production in the country, 33% comes from the central highland region (CSA, 1997a).

As in many other tropical and subtropical regions (Sanchez, 1976), soils in the highlands of Ethiopia, particularly in the central region, exhibit low levels of essential plant nutrients and organic matter content (Asnakew *et al.*, 1991; Tekalign *et al.*, 1988). Poor soil fertility (Amsal *et al.*, 1997a), especially low availability of N and P (Asnakew *et al.*, 1991; Tekalign *et al.*, 1988), has been demonstrated to be a major constraint to wheat production in Ethiopia. This is largely a consequence of the cereal-dominated cropping history of most fields and continuous nutrient mining by crop removal (Amsal *et al.*, 1997b; Amanuel *et al.*, 1991), which eventually lead to depletion of soil nutrients (Asnakew *et al.*, 1991; Tanner *et al.*, 1993). Soil nutrient depletion has been exacerbated by low levels of chemical fertilizer usage (Asnakew *et al.*, 1991; CSA, 1997b) due to both high cost and constraints to timely availability of the fertilizer input (Gezahegn and Tekalign, 1995).

In the central highland region, wheat production utilizes 27% of the total annual fertilizer consumption by wheat in the country (Asnakew *et al.*, 1991). In this region, poor soil fertility is aggravated by the loss of plant nutrients from the crop root zone due to intense leaching and runoff on Nitisols; denitrification is common on frequently waterlogged Vertisols particularly during the heavy rains from June to September. Consequently, nutrient deficiency, especially for N and P, is often encountered in wheat crops growing in cool, wet areas, including the poorly drained Vertisols (Asnakew *et al.*, 1991; Tekalign *et al.*, 1988, Tanner *et al.*, 1993; Tilahun *et al.*, 1996).

The quantity of fertilizer nutrients required to optimize crop production depends on the inherent capacity of the soil to supply adequate levels of nutrients to growing plants (Sanchez 1976; Baligar and Bennett, 1986), the yield potential of the crop variety grown (Amsal *et al.*, 1995, 1997a; Tilahun *et al.*, 1996), the availability and cost of fertilizers (Gezahegn and Tekalign, 1995), and climatic conditions prevailing during the crop growing season (Baligar and Bennett, 1986). Due to the recent release of improved high-yielding bread wheat varieties adapted to heterogeneous environmental conditions in Ethiopia (Hailu, 1991; Payne *et al.*, 1996), wheat grain yield potential has significantly increased in Ethiopia (Amsal *et al.*, 1995) and area coverage has substantially expanded (Payne *et al.*, 1996) mainly by replacing unimproved, input non-responsive traditional cereal crops such as tef, durum wheat (*T. durum*) and barley (*Hordeum vulgare*) (Getachew *et al.*, 1993; CSA, 1997a). Recently released cultivars are highly responsive to improved crop management systems (Amsal *et al.*, 1999) and require higher rates of nutrient applications (Tanner *et al.*, 1993; Amsal *et al.*, 1997a). The Broad Bed and Furrow (BBF) system introduced in the mid 1980s (ILCA, 1989) to improve surface drainage has substantially increased bread wheat production and productivity on poorly-drained Vertisols (Mesfin *et al.*, 1994) where crop production has been historically restricted to low-yielding traditional crops (Getachew *et al.*, 1993).

Studies elsewhere (Greenwood, 1981; Baligar and Bennett, 1986) have demonstrated that application of fertilizer greatly increases crop yields, facilitates the adoption of high-yielding improved varieties, and provides a high amount of crop residue which can be used to improve soil fertility and prevent soil degradation. Greater usage of chemical fertilizers has been hailed by many workers (Asnakew *et al.*, 1991; Tanner *et al.*, 1993; Amsal *et al.*, 1997a, 1999) as a primary means of increasing wheat grain yields in Ethiopia. Accordingly, the demand for DAP (di-ammonium phosphate) and urea, the two most commonly used fertilizer sources in Ethiopia, was projected to increase annually by 16 and 11%, respectively, between 1998 and 2001 (FEWS/LFSU, 1998).

Currently, extension personnel disseminate a fertilizer rate equivalent to 60 kg N and 60 kg P_2O_5 ha^{-1} for wheat production in central Ethiopia. This recommendation was derived in the early 1970s and was based on results generated from on-station trials, unrepresentative of current peasant farmers' wheat fields; tall, low-yielding and input non-responsive old cultivars were used in these trials with no intervention to improve soil drainage for frequently waterlogged wheat in the Vertisol zones. To date, however, wheat production in central Ethiopia has exhibited a significant change in cropping practices mainly due to the increased availability of chemical fertilizers at a fair price (GMRP, 1997), a wide range of input-responsive high-yielding semi-dwarf cultivars (Hailu, 1991; Payne *et al.*, 1996; Amsal *et al.*, 1999) and the introduction of improved drainage technologies (ILCA, 1989) to enhance productivity in Vertisol areas (Mesfin *et al.*, 1994). It is, therefore, imperative to revise the current fertilizer recommendation and generate new zone-specific, economically optimal N and P fertilizer rates for the wheat production systems in the central highland region. Recently, researchers in the south-eastern and north-western wheat growing regions of the country have conducted a series of on-farm fertilizer response trials and generated new zone-specific economically optimum N and P rates for wheat production (Amanuel *et al.,* 1991; Tanner *et al.*, 1999). The results from those trials indicated not only an increase in wheat yields and net return to the farmers, but also demonstrated the advantages of zone-specific fertilizer recommendations in sustaining wheat production in the highlands of Ethiopia.

This paper summarizes the results of 14 on-farm N and P fertilizer trials conducted on two contrasting soil types (i.e., well-drained highly-weathered Nitisols and frequently waterlogged Vertisols) in the central highlands of Ethiopia. The objectives were to examine yield and yield component response of a recently released high-yielding bread wheat variety to applied N and P fertilizer rates, and to generate economically optimal N and P fertilizer rates for bread wheat production in specific agro-ecological zones in central Ethiopia.

MATERIALS AND METHODS

Locations and climatic conditions. The experiment was conducted during the 1995 and 1996 main cropping seasons on farmers' fields in well-drained highly-weathered reddish-brown soil (eutric Nitisol) and in poorly-drained heavy dark clay soil (pellic Vertisol) zones of west Shewa in the central highland of Ethiopia. In each zone, seven trials were conducted on representative farm sites selected annually in conjunction with local extension agents. Details of the trial sites and soil characteristics are presented in Table 1. All soil characteristics were determined at the Holetta Research Center analytical laboratory using soils sampled at 0-30 and 31-60 cm depths from each site prior to trial planting in late June. Climatic data during each trial season were obtained from the closest weather station (i.e., from Holetta R.C. in the Nitisol zone and the Ginchi R.C. in the Vertisol zone). Accordingly, mean annual rainfall was 649.0 and 787.6 mm at Holetta and 648.5 and 725.4 mm at Ginchi during the 1995 and 1996 cropping seasons, respectively. The corresponding mean minimum and maximum temperatures were 5.9 and 6.3°C and 20.9 and 21.5°C at Holetta and 7.8 and 7.1°C and 23.6 and 23.0°C at Ginchi, respectively.

Treatments and experimental design. This experiment examined the response of bread wheat to treatments consisting of the 12 factorial combinations of four N rates (i.e., 20.5, 41, 82 and 164 kg ha^{-1}) from urea and three P_2O_5 rates (i.e., 23, 46 and 92 kg ha^{-1}) from triple super phosphate, plus a control with no fertilizer application. The treatments were laid out in a randomized complete block design with three replications at each site. The trials were

planted with a gross plot size of 4.8 x 5 m (= 24 m^2) in the Vertisol zone and 4 x 5 m (= 20 m^2) in the Nitisol zone.

Host farmers, according to their customary practices and using the traditional ox-plow system, prepared the trial seedbeds. The BBF drainage system, using a 0.8 m wide raised bed and a 0.4 m wide furrow, was superimposed at planting for all trials in the Vertisol zone to facilitate drainage of excess surface water during the crop growing season. All P fertilizer was applied at planting, while N fertilizer was split applied (Tilahun *et al.,* 1996): one-third of N was applied at planting and the remainder was top-dressed at mid-tillering.

Host farmers selected sowing dates: all trials were sown from the latter half of June to the first week of July across the two years. Immediately after surface broadcast application of the basal N portion and all P fertilizer, a pre-weighed quantity of seeds of the bread wheat variety "Kubsa" was broadcast sown at the rate of 150 kg ha^{-1}, then soil-incorporated by constructing BBFs in the Vertisol zone and by one pass of the local ox-plow in the Nitisol zone (i.e., as per farmers' practice). The bread wheat variety "Kubsa", a semi-dwarf high-yielding variety selected from CIMMYT germplasm (= "Atilla"), was released in 1993 on a national scale. Weeds were controlled by post-emergence spraying of 2,4-D at the rate of 1.5 l product ha^{-1} at 25 DAE and Puma S at the rate of 1.0 l product ha^{-1} at 55 DAE in all trials.

Plant height and the number of productive spikes m^{-2} were determined for each treatment prior to plot harvest. Numbers of kernels $spike^{-1}$ were determined from 20 spikes sampled at random from each plot. At physiological maturity, plants from a net plot size of 3 x 4 m were hand-harvested close to the ground surface using sickles. The harvests were sun-dried in the open air, weighed to determine the above-ground biomass yield, then threshed and grain yields were weighed for each treatment. Harvest index was determined as the ratio of grain yield to above-ground biomass yield and expressed as a percentage. Thousand-kernel weight was determined by weighing 1000 seeds randomly sampled from each plot yield. The number of grains m^{-2} was determined as the product of the number of productive spikes m^{-2} and seeds $spike^{-1}$.

Statistical and economic analysis. All data were subjected to combined analysis of variance (ANOVA) using MSTATC microcomputer software.

The 13 N by P interaction means for grain yield (GY) for both trial sets were fitted to the following response surface by multiple regression analysis:

$$GY = a + b_1(N) + b_2(P_2O_5) + b_3(N)^2 + b_4(P_2O_5)^2 + b_5(N)(P_2O_5)$$

The coefficients thus derived were used to determine economic optimum N and P_2O_5 rates according to the methodology of Jauregui and Sain (1992) for continuous economic analysis of crop response to fertilizer. Specifically, for each nutrient an "r" value was calculated; the economic optimum nutrient level was found by equating the partial derivatives of the response surface to the respective "r" value, and solving for nutrient rate. For each nutrient, "r" was determined from the equation:

$$r = P_F\,(1 + R)/(P_{OS} - C_Y)(1 - a)$$

where P_F = fertilizer price per kg of nutrient
R = the minimum acceptable rate of return (MARR): set at 1.0 (=100%)

in this analysis
P_{OS} = farmer price per kg of grain
C_Y = cost of harvest, threshing and transport; set at 0.22 Ethiopian Birr kg^{-1} in this analysis
a = adjustment of experimental grain yields to minimize bias: set at 0.10 (=10%) in this analysis

The 13 mean grain yields for the N by P treatment combinations for each trial set were also subjected to discrete economic analysis using partial budget methodology (CIMMYT, 1988). The partial budget analysis utilized the same assumptions regarding adjustments, costs/prices, and the MARR as described for the continuous economic analysis.

To compare the two methods of economic analysis, three cost/price scenarios were used for each trial set as shown in the following table:

	Scenario 1 Low Fertilizer: High Grain Price	**Scenario 2 Mod. Fertilizer: Moderate Grain**	**Scenario 3 High Fertilizer: Low Grain Price**
Wheat grain price (EB/kg)	1.50	1.20	0.90
N cost[a] (EB/kg N)	3.6	4.1	5.1
P_2O_5 cost[b] (EB/kg P_2O_5)	3.0	3.4	4.2

[a]Derived from the cost of urea (i.e., cost of N per kg = cost of urea per kg/0.46).
[b]Derived from the cost of DAP (i.e., cost of P_2O_5 per kg = cost of DAP per kg/0.64).

The value of wheat straw was ignored in the current economic analysis as per the approach of Amanuel *et al.* (1991). Wheat straw has a significant market value in relatively few locations throughout Ethiopia. Thus, the exclusion of this product from the economic analysis is justifiable, and represents an additional element of conservatism in the derived economic optimum nutrient rates.

RESULTS AND DISCUSSION

Agronomic analysis. The results of the combined analysis of the N by P trials (i.e., seven site-year combinations within each soil zone) are presented in Table 2 for the Vertisol and Table 3 for the Nitisol. The two soil zones were markedly different in grain yield (GY) potential as reflected in the trial means of 1.89 t/ha on the Vertisol and 3.08 t/ha on the Nitisol. Mean GY of the control (i.e., no fertilizer applied) was also lower on the Vertisol (0.72 t/ha) cf. the Nitisol (1.75 t/ha).

Application of N and P significantly increased all crop parameters studied in both soil zones relative to the control treatment (Tables 2 and 3) except HI on the Nitisol. The mean GY response to fertilizer application was 163% on the Vertisol and 76% on the Nitisol cf. the unfertilized control. Mean wheat biomass yield (BY) increased by 149% on the Vertisol and 77% on the Nitisol cf. the control treatment. On both soil types, fertilizer application

produced taller plants, a larger number of spikes m^{-2} (SPM), heavier thousand grain weight (TGW), and more grains m^{-2} (GPM) cf. unfertilized wheat.

In the Vertisol zone, all measured wheat crop parameters exhibited a positive but quadratic (i.e., diminishing) response to applied N fertilizer except SPM (Table 2); SPM did not exhibit either a linear or quadratic response to N. Wheat GYs increased by 83, 156, 233 and 288% in response to the application of 20.5, 41, 82 and 164 kg N ha^{-1}, respectively; grain conversion ratios for the respective rates of applied N were 29.3, 27.3, 20.4 and 12.6 kg grain per kg N applied.

In the Nitisol zone, all measured wheat crop parameters exhibited a positive and linear (i.e., constant rate) response to applied N fertilizer except HI and BY (Table 3); HI did not exhibit either a linear or quadratic response to N, while BY exhibited a positive but quadratic response to N. Wheat GYs increased by 45, 62, 98 and 150% in response to the application of 20.5, 41, 82 and 164 kg N ha^{-1}, respectively; grain conversion ratios for the respective rates of applied N were 38.5, 26.3, 20.9 and 16.0 kg grain per kg N applied.

The application of P_2O_5 resulted in a positive but quadratic response for SPM, GPM, BY and GY in the Vertisol zone (Table 2). Plant height (PH) and TGW exhibited a positive and linear response to P_2O_5, while HI showed no response to P_2O_5. Application of 23, 46 and 92 kg P_2O_5 ha^{-1} resulted in a GY increment of 171, 196 and 203%, respectively; grain conversion ratios for the respective rates of applied P_2O_5 were 53, 31 and 16 kg grain per kg P_2O_5 applied.

In the Nitisol zone, only TGW exhibited a positive but quadratic response to the application of P_2O_5 (Table 3). PH, BY and GY exhibited a positive and linear response to P_2O_5, while SPM, GPM and HI showed no response to P_2O_5. Application of 23, 46 and 92 kg P_2O_5 ha^{-1} resulted in a GY increment of 71, 90 and 104%, respectively; grain conversion ratios for the respective rates of applied P_2O_5 were 54, 34 and 20 kg grain per kg P_2O_5 applied.

Across both zones, all N by P_2O_5 interaction terms were non-significant for the crop parameters studied except the N quadratic by P_2O_5 quadratic interaction term ($P<0.01$) for PH in the Nitisol zone.

The coefficients of the response surfaces developed by regression analysis for each soil zone are listed in Table 4. The b_1 and b_2 coefficients represent the "slopes" of the response surfaces at 0 N and 0 P_2O_5, respectively, b_3 and b_4 represent the quadratic "pull down" effect of the diminishing response to incremental units of each nutrient, and b_5 represents the effect of interaction between the nutrients on GY. Both regressions listed in Table 4 were significant at the 0.1% level and accounted for 97.3 to 98.3% of the variation in the 13 GY means used in the regression.

Economic analysis. Economic optimum nutrient rates for each soil zone, derived by solving the partial derivatives of each response surface for the permutations of a range of N, P and grain prices, can be presented in tabular format for ease of interpretation by extension staff and policy-makers (Tables 5 and 6). For example, the optimum nutrient rate for Kubsa in the Nitisol zone is 112 kg N and 46 kg P_2O_5 ha^{-1} when the prices of N, P_2O_5 and grain are 4.1, 3.8 and 1.2 EB kg^{-1}, respectively (Table 5).

Tabular presentation of optimal nutrient rates for the various grain and nutrient price permutations (Tables 5 and 6) presents three distinct potential benefits for wheat producers in Ethiopia. First, and perhaps most importantly, such tables provide a dynamic template for extension staff to use when determining rates of N and P_2O_5 to recommend: recommended nutrient rates should be based on nutrient prices immediately prior to planting and on projected grain prices for farmers. Such price-sensitive flexibility represents a marked contrast to previous fertilizer recommendations which were based on fixed prices at a given point in time, and were often issued on a national scale, neglecting zone-specific environmental heterogeneity. As an example, recent national nutrient recommendations for "wheat" (i.e., not even specifically targeted for bread or durum wheat) consisted of 36 kg N and 31 kg P_2O_5/ha for "red and brown soils" and 56 kg N and 6 kg P_2O_5/ha for "black and grey soils" (NFIU, 1989). Even where sensitivity analysis has been included in the economic analyses, the range of prices has tended to be limited in magnitude (Amanuel *et al.*, 1991).

The second potential benefit of such a tabular presentation of optimum nutrient rates is that it facilitates interpolation for grain and nutrient prices intermediate to the intervals used to generate the tables. Such interpolation by extension staff should, in theory, maximize the economic efficiency of fertilizer usage in wheat production in Ethiopia.

Thirdly, such tables can provide valuable insights for policy-makers when estimating the potential impact of policy interventions affecting grain and nutrient price levels, such as the removal of subsidies: policy and resultant price changes will alter fertilizer profitability, recommended nutrient rates, national grain production levels, and the requirements for imported grain and/or fertilizer.

The major limitation to the modeling approach employed to generate optimum nutrient rate tables is that the validity of the outputs can occasionally be critically affected by the coefficients of the estimated response surfaces even when there is no apparent violation of the prerequisite conditions for continuous economic analysis (Tanner *et al.*, 1999).

The "goodness-of-fit" of the economic optimum nutrient rates derived from the response surface coefficients cf. the rates determined to be optimal by discrete economic analysis are presented for the three specific price scenarios described in the Materials and Methods: low fertilizer and high grain prices, moderate prices for both, high fertilizer and low grain prices (Table 7). It should be emphasized that the optimal rates determined by using the two methods will seldom be equal since discrete analysis is based on the actual GY response points while continuous analysis is based on response surfaces "smoothed" by regression analysis. As per the recommendations of Tanner *et al.* (1999), fertilizer response GY data should be subjected simultaneously to discrete and continuous economic analysis to increase the level of confidence in recommendations arising from the analysis.

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Questions and Answers:

Colin Wellings: A general question to those undertaking nutrition and fertilizer response studies: Has there been any value in using soil testing as a diagnostic predictor of fertilizer response?

Answer (D.G. Tanner): There are significant correlations between soil nitrate and available P and N and P response, respectively. However, the predictive values are low. Also, soil lab capacity is too low to make diagnostics practical.

Table 1. Characteristics and results of soil analysis of 14 experimental sites.

Location	Sowing date	Altitude (m)	Previous crop	Soil depth (cm)	Soil particle size			Organic Carbon	pH				Exchangeable cations				CEC
					Sand	Silt	Clay			P	NO_3	NH_4	Na	K	Ca	Mg	
					(%)			(%)	(1:1) H_2O	(ppm)			(meq/100 g)				
pellic Vertisol																	
Amaro A	15/06/1995	2400	Wheat	00-30	10.00	16.25	73.25	1.36	7.29	3.98	7.00	7.00	0.21	2.35	36.32	5.52	35.80
				31-60	7.5	20.00	72.50	1.17	7.41	2.98	5.60	14.00	0.30	2.33	51.15	5.62	54.60
Amaro B	15/06/1995	2400	Fenugreek	00-30	7.5	18.75	73.75	1.21	7.19	4.68	2.80	4.20	0.24	2.37	65.60	5.44	57.40
				31-60	10.00	16.25	73.73	1.21	7.40	5.10	2.80	7.00	0.26	2.37	34.90	5.53	57.60
Amaro B	18/061996	2410	Fenugreek	00-30	17.50	15.00	67.50	1.09	7.35	5.80	32.20	22.40	0.44	2.46	76.35	5.96	63.80
				31-60	17.50	13.75	68.75	1.05	7.60	3.80	14.00	18.20	0.36	2.01	78.47	6.44	63.00
Boche	20/06/1995	2150	Noug	00-30	7.50	21.25	71.25	1.21	6.41	7.66	5.60	11.20	0.50	2.23	42.23	5.88	34.80
				31-60	7.50	22.50	70.00	1.32	6.54	8.08	2.80	7.00	0.69	2.17	41.84	5.83	44.00
Boche	02/07/1995	2150	Wheat	00-30	16.25	16.25	67.50	1.13	7.00	12.80	9.80	9.80	0.80	2.30	52.09	7.78	60.40
				31-60	15.00	17.50	67.50	1.01	7.25	9.80	9.80	18.20	0.80	1.79	51.42	8.28	62.40
Borodo	20/06/1995	2175	Chickpea	00-30	10.00	18.75	71.25	1.21	6.06	2.26	5.60	4.20	0.60	1.93	40.13	5.63	49.00
				31-60	15.00	13.75	71.25	1.17	6.09	2.12	Trace	Trace	0.80	1.82	42.23	5.66	47.00
Borodo	02/07/1996	2200	Tef	00-30	16.25	21.25	62.50	1.32	7.03	7.40	18.20	22.40	0.48	1.76	31.89	6.43	53.80
				31-60	18.75	15.00	66.25	0.90	6.52	6.40	14.00	28.00	0.66	1.70	37.89	6.44	56.80
Nitisol																	
Negade-Sororo	21/06/1995	2225	Sorghum	00-30	12.50	28.75	58.75	1.91	5.87	3.68	4.20	47.60	0.13	1.24	24.58	5.40	27.60
				31-60	15.00	23.75	61.25	1.56	6.00	3.26	8.40	33.60	0.18	1.33	22.65	5.38	27.00
Negade-Sororo	22/06/1996	2200	Sorghum	00-30	21.25	23.75	55.00	1.87	5.08	2.40	28.00	14.00	0.46	1.45	21.54	5.13	33.60
				31-60	12.50	17.50	70.00	1.17	5.20	2.00	22.40	9.80	0.45	0.85	19.91	6.27	31.60
Menag-esha	22/06/1995	2525	Fallow	00-30	12.50	28.75	58.75	2.18	5.22	3.40	4.20	18.20	0.08	1.39	10.89	3.88	16.20
				31-60	10.00	26.25	63.75	1.52	4.95	2.84	5.60	9.80	0.11	1.08	10.82	3.96	20.20
Menag-esha	21/06/1996	2580	Fallow	00-30	25.00	26.25	48.75	1.87	4.50	3.00	26.60	23.80	0.35	1.35	11.83	2.13	25.50
				31-60	22.50	17.50	60.00	0.97	4.63	3.00	14.00	14.00	0.35	1.05	10.75	2.02	23.80
Wolmera	21/06/1996	2350	Wheat	00-30	27.50	25.00	47.50	1.44	4.95	6.20	22.40	21.00	0.32	1.29	15.93	3.37	25.60
				31-60	22.50	21.25	56.25	1.32	5.15	5.00	28.00	11.20	0.28	1.35	17.26	3.19	28.80
Chiri	22/06/1996	2400	Tef	00-30	20.00	22.50	57.50	1.60	5.05	14.00	32.20	22.40	0.36	2.63	15.09	3.31	27.00
				31-60	12.50	20.00	67.50	0.94	5.80	3.60	9.80	4.20	0.42	2.93	15.20	4.06	25.60
G. Kuyu	22/06/1996	2475	Barley	00-30	22.50	27.50	50.00	1.52	4.45	6.80	18.20	4.20	0.39	1.07	10.16	1.98	26.00
				31-61	20.20	17.50	62.50	1.09	4.60	9.40	18.20	9.80	0.34	0.74	8.18	1.86	26.00

Table 2. The effects of fertilizer N and P application rates on selected agronomic parameters of wheat grown on a Vertisol.

	PH (cm)	SPM (no. m^{-2})	TGW (g)	GPM[a] (no. m^{-2})	HI (%)	BY (t ha^{-1})	GY (t ha^{-1})
kg N ha^{-1}							
20.5	72	430	32.1	7.86	37.6	3.54	1.32
41	77	468	33.5	9.92	39.0	4.73	1.84
82	81	441	35.4	11.0	41.0	5.88	2.40
164	82	467	35.9	12.6	42.1	6.72	2.79
kg P_2O_5 ha^{-1}							
23	76	407	33.9	8.96	39.9	4.85	1.95
46	78	467	34.1	11.0	40.0	5.34	2.13
92	80	481	34.6	11.1	39.8	5.47	2.18
Control	57	316	30.2	3.82	38.3	1.91	0.72
Mean	75	432	33.6	9.42	39.7	4.75	1.89
C.V.(%)	4.4	22.1	4.9	26.0	9.3	12.6	12.8
Control vs. fertilizer[b]	***	***	***	***	*	***	***
N_{linear}	***	NS	***	***	***	***	***
$N_{quadratic}$	***	NS	***	*	*	***	***
P_{linear}	***	***	*	***	NS	***	***
$P_{quadratic}$	NS	*	NS	**	NS	*	*
N_{linear} x P_{linear}	NS	NS	NS	NS	NS	NS	NS
N_{linear} x $P_{quadratic}$	NS	NS	NS	NS	NS	NS	NS
$N_{quadratic}$ x P_{linear}	NS	NS	NS	NS	NS	NS	NS
$N_{quadratic}$ x $P_{quadratic}$	NS	NS	NS	NS	NS	NS	NS

[a] Value scaled by 10^{-3}.

[b] Single degree of freedom orthogonal contrast.

*, **, *** Significant at the 5, 1 and 0.1% level, respectively.

Table 3. The effects of fertilizer N and P application rates on selected agronomic parameters of wheat grown on a Nitisol.

	PH (cm)	SPM (no. m^{-2})	TGW (g)	GPM[a] (no. m^{-2})	HI (%)	BY (t ha^{-1})	GY (t ha^{-1})
kg N ha^{-1}							
20.5	78	524	36.0	14.2	46.6	5.55	2.54
41	80	532	36.2	15.4	42.5	6.54	2.83
82	82	546	37.0	16.0	42.4	8.13	3.46
164	86	634	37.1	20.3	42.4	10.28	4.37
kg P_2O_5 ha^{-1}							
23	80	564	35.7	16.5	42.7	6.99	3.00
46	82	556	36.8	15.8	45.1	7.58	3.32
92	83	557	37.2	17.1	42.6	8.30	3.57
Control	69	508	33.2	11.2	42.6	4.01	1.75
Mean	80	552	36.1	15.7	43.4	7.11	3.08
C.V.(%)	3.3	16.5	4.6	20.4	25.0	11.9	16.0
Control vs. fertilizer[b]	***	*	***	***	NS	***	***
N_{linear}	***	***	**	***	NS	***	***
$N_{quadratic}$	NS	NS	NS	NS	NS	**	NS
P_{linear}	***	NS	***	NS	NS	***	***
$P_{quadratic}$	NS	NS	†	NS	NS	NS	NS
N_{linear} x P_{linear}	NS	NS	NS	NS	NS	NS	NS
N_{linear} x $P_{quadratic}$	NS	NS	NS	NS	NS	NS	NS
$N_{quadratic}$ x P_{linear}	NS	NS	NS	NS	NS	NS	NS
$N_{quadratic}$ x $P_{quadratic}$	**	NS	NS	NS	NS	NS	NS

[a] Value scaled by 10^{-3}.

[b] Single degree of freedom orthogonal contrast.

†, *, **, *** Significant at the 10, 5, 1 and 0.1% level, respectively.

Table 4. Parameters of N and P response surfaces[a] generated from bread wheat grain yields in OFFTs conducted during 1995-96.

Zone	Sites	Years	n	a	b_1	b_2	b_3	b_4	b_5	Sig.	R^2
Nitisol	7	1995-96	13	1358 ***	18.03 ***	11.27 †	-0.042 *	-0.0452	0.0138	***	97.3
Vertisol	7	1995-96	13	763 ***	22.14 ***	8.051 †	-0.0811 ***	-0.06	0.0375 *	***	98.3

†, *, *** Indicate significance at the 10, 5, and 0.1% level, respectively.

[a] Grain yield data fitted to following surface: Grain yield (kg ha^{-1}) = $a + b_1(N) + b_2(P_2O_5) + b_3(N)^2 + b_4(P_2O_5)^2 + b_5(N)(P_2O_5)$

Table 5. Economic optimum N and P_2O_5 rates (kg ha^{-1}) determined for Kubsa bread wheat cultivar in the Nitisol zone based on the response surface generated from grain yields in OFFTs (7 sites, 1995-96).

		Price per kg N															
		3.6				4.1				4.6				5.1			
	Price per kg P_2O_5	3.0	3.4	3.8	4.2	3.0	3.4	3.8	4.2	3.0	3.4	3.8	4.2	3.0	3.4	3.8	4.2
Price per kg grain																	
	1.5	155-91	154-83	153-75	151-67	145-89	143-81	142-73	141-66	134-88	133-80	131-72	130-64	123-86	122-78	121-70	119-62
	1.4	148-85	146-76	145-68	144-59	136-83	135-75	134-66	132-57	125-81	123-73	112-64	121-56	113-80	112-71	111-62	109-54
	1.3	139-78	138-68	136-59	135-50	127-76	125-66	124-57	122-48	114-74	113-65	111-55	109-46	102-72	100-63	98-53	97-44
	1.2	129-69	127-59	125-49	124-38	115-67	113-57	112-46	110-36	101-65	99-55	98-44	96-34	87-63	86-53	84-42	82-32
	1.1	116-59	114-47	112-36	110-24	101-56	99-45	97-33	95-22	85-54	83-43	81-31	80-20	70-52	68-40	66-29	64-17
	1.0	100-45	98-33	96-20	94-7	83-43	80-30	78-17	76-4	65-40	63-27	61-14	59-1	48-37	46-25	44-12	41-0
	0.9	79-28	77-14	74-0	74-0	59-25	57-10	54-0	54-0	39-22	37-7	34-0	34-0	19-19	17-4	14-0	14-0

All grain and nutrient prices expressed in Ethiopian Birr (EB) per kg. 1 US$ = 8.2 EB (May, 2000).

Table 6. Economic optimum N and P_2O_5 rates (kg ha^{-1}) determined for Kubsa bread wheat cultivar in the Vertisol zone based on the response surface generated from grain yields in OFFTs (7 sites, 1995-96).

		Price per kg N															
		3.6				4.1				4.6				5.1			
	Price per kg P_2O_5	3.0	3.4	3.8	4.2	3.0	3.4	3.8	4.2	3.0	3.4	3.8	4.2	3.0	3.4	3.8	4.2
Price per kg grain																	
	1.5	112-59	110-52	109-46	107-40	106-57	104-51	103-44	101-38	100-55	99-49	97-42	96-36	94-53	93-47	91-41	90-34
	1.4	107-53	106-47	104-40	102-33	101-52	99-45	98-38	96-31	95-50	93-43	91-36	90-29	88-48	87-41	85-34	84-27
	1.3	102-47	100-40	98-33	97-25	95-45	93-38	92-31	90-23	88-43	86-36	85-28	83-21	81-41	80-34	78-26	76-19
	1.2	96-40	94-32	92-24	90-16	88-38	86-30	84-22	82-13	80-36	79-27	77-19	75-11	73-33	71-25	69-17	67-9
	1.1	88-31	86-22	84-13	81-4	79-29	77-20	75-11	73-2	71-26	69-17	67-8	65-0	63-24	60-14	58-5	56-0
	1.0	78-20	76-10	73-0	73-0	68-17	66-7	64-0	64-0	59-14	57-4	54-0	54-0	50-11	47-1	45-0	45-0
	0.9	65-6	63-0	63-0	63-0	54-2	52-0	52-0	52-0	44-0	44-0	44-0	44-0	33-0	33-0	33-0	33-0

All grain and nutrient prices expressed in Ethiopian Birr (EB) per kg. 1 US$ = 8.2 EB (May, 2000).

Table 7. A comparison of the economic optimum N and P_2O_5 rates (kg ha^{-1}) determined by discrete and continuous economic analysis of the OFFTs conducted during 1995-96 under three cost/price scenarios.

				Technical optimum		Economic optimum					
						Scenario 1		Scenario 2		Scenario 3	
Zone	Sites	Years	Cv.	N-P (kg/ha)	GY (kg/ha)	Cont. N-P (kg/ha)	Discrete N-P (kg/ha)	Cont. N-P (kg/ha)	Discrete N-P (kg/ha)	Cont. N-P (kg/ha)	Discrete N-P (kg/ha)
Nitisol	7	1995-96	Kubsa	241-162	4000	155-91	164-46	113-57	82-92	16-0	0-0
Vertisol	7	1995-96	Kubsa	164-118	2748	112-59	82-46	86-30	82-46	34-0	0-0

EFFECTS OF SOIL WATERLOGGING ON THE CONCENTRATION AND UPTAKE OF SELECTED NUTRIENTS BY WHEAT GENOTYPES DIFFERING IN TOLERANCE

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ABSTRACT

Waterlogging of soil may restrict crop performance by altering soil mineral nutrient availability to and uptake by roots. A greenhouse experiment was conducted in 1998/99 using a soil high in clay content (Vertisol), at the University of the Orange Free State, South Africa, to determine the effects of soil waterlogging on Cu, Zn, P and K nutrient concentration and uptake by wheat genotypes that differ in tolerance to waterlogging. Differential response of wheat genotypes to waterlogging treatments was observed on vegetative dry biomass, straw and grain yields. Root zone oxygenation was significantly depressed by the waterlogging treatments as indicated by significantly reduced soil redox potentials. Both waterlogging and genotype treatments significantly affected the uptake and concentration of most of the nutrients in the vegetative biomass at anthesis or in the straw and grain at maturity. A significant differential response of wheat genotypes to waterlogging treatments was detected for most nutrient concentrations and uptake parameters. Compared to waterlogging tolerant genotypes, sensitive genotypes appeared to accumulate less Cu, Zn, P and K. There was a considerable difference between waterlogging-sensitive and tolerant wheat genotypes reflected in the accumulation and uptake of these nutrients under waterlogging stress; the damaging effects of waterlogging were therefore attributed to decreased nutrient uptake due to O_2 deficiency in the root zone, in particular resulting in P and Zn deficiency. Selection of genotypes with enhanced ability to overcome waterlogging-induced nutrient deficiency, particularly P and Zn deficiency, should improve wheat productivity in waterlogged soils.

INTRODUCTION

Soil waterlogging adversely affects the growth of terrestrial plants (Kozlowski; 1990), primarily due to reduced oxygen (O_2) supply to the roots (Grable, 1966; Armstrong 1982). Mineral nutrition of waterlogged crop plants may be largely affected by the initial nutrient status of the soil, changes in soil physicochemical properties and tolerance capabilities of the crop varieties (Kozlowski, 1990). In waterlogged soils, the pore spaces that usually allow free gas exchange between the rhizosphere and atmosphere are filled with water, which severely reduce the diffusion of O_2 into the soil (Grable, 1966). Water covering the soil slows O_2 diffusion from the atmosphere by a factor of 10^{-4} (Armstrong, 1979). Respiration by roots and soil microorganisms may deplete O_2 dissolved in the soil solution within a day of waterlogging (Drew and Lynch, 1980; Ponnamperuma, 1984).

Due to the restriction of gas exchange and subsequent depletion of O_2, some soil microorganisms make use of electron acceptors other than O_2 for their respiratory oxidation (Ponnamperuma, 1984; Armstrong, 1982) thereby promoting a series of chemical and microbiological changes in the soil (Armstrong 1982). These changes result in the accumulation of CO_2 and several organic compounds to levels toxic to plant roots (Drew and Stolzy, 1996; Armstrong, 1982) and reduction of NO_3-N, Fe, Mn, and sulfate, and changes in pH and redox potential of the soil (Armstrong, 1982; Ponnamperuma, 1984; Krizek, 1990; Laanbroek, 1990).

The mineral composition of cultivated plants under waterlogged conditions depends largely on soil O_2 availability. It has been indicated that soil waterlogging results in reduced foliage concentrations of P and K in wheat (Drew and Sisworo, 1979). Stieger and Feller (1994) reported that waterlogging during grain filling reduced grain yield as well as K, P and Zn concentrations in the shoots and grains of wheat. Leyshon and Sheard (1974) obtained a reduction in P and K concentration of 61 and 58%, respectively, in barley seedlings following short-term waterlogging. Waterlogging of barley for 10 days decreased the P and K concentrations in grains (Stepniewski and Labuda, 1984). In a field study using wheat and pearl millet, Sharma and Swarup (1989) reported that short-term waterlogging decreased P, K and Zn uptake by the grain and straw. Huang *et al.* (1995) reported a reduction in P, K and Zn concentrations in the shoots and an increase of these nutrients in the roots of winter wheat. Waterlogging-induced O_2 deficiency may inhibit nutrient uptake and transport in waterlogging-sensitive crop varieties (Kozlowski, 1990) by altering root function due to the death of root system (Drew and Lynch, 1980; Stepniewski and Przywar, 1992; Trought and Drew, 1980a and b), causing nutrient leakage due to loss of integrity in root cell membranes (Resen and Carlson, 1984), or providing sub-optimal energy for active ion uptake due to inefficient anaerobic metabolism (Barrett-Lennard *et al.*, 1990; Setter and Belfod, 1990).

Waterlogging is a serious environmental constraint to wheat production on poorly drained soils (Kozlowski, 1984). Vertisols with a high montmorillonite clay content are important agricultural soils in cool and wet wheat growing agro-ecologies of the central and eastern African highlands (Jutzi and Abebe, 1986). Wheat genotypes differ in their tolerance to waterlogging stress (van Ginkel *et al.*, 1992). Wheat production on frequently waterlogged Vertisols such as these of the eastern African highlands could likely be improved when planted to waterlogging tolerant genotypes. Little is known about the nutrient uptake and accumulation by wheat genotypes differing in waterlogging tolerance (Huang *et al.*, 1995). Hence, research is needed to determine whether a genotypic difference in waterlogging tolerance in wheat can be related to differences in nutrient acquisition and uptake. This study was therefore conducted to determine the effects of soil waterlogging on the Cu, Zn, P and K nutrient concentrations and uptakes by wheat genotypes identified under field and greenhouse conditions to differ in waterlogging tolerance.

MATERIALS AND METHODS

A virgin Vertisol (ca. 46% clay) was used in the greenhouse to fill three liter size polyethylene pots perforated at the bottom. Sufficient soil from the top 0-20 cm depth layer was collected from Glen Agricultural College campus, located about 30 km north of Bloemfontein, South Africa. The soil was pulverized and sieved to remove clogs and fibrous root materials, thoroughly mixed with N and P nutrient solution at the rate of 70 mg N as KNO_3 and 35 mg P as K_2HPO_4 kg^{-1} soil. Before filling the pots with 3 kg soil, 150 g gravel was placed at the bottom to facilitate drainage of the pots.

Five bread wheat genotypes consisting of two waterlogging-sensitive, "Et-13" and "K6290-Bulk", and three waterlogging-tolerant, "PRL/Sara", "Vee/Myna", and "Ducula"), were selected based on their performance in an on-going genotype screening experiment for waterlogging tolerance. The latter three genotypes were previously identified in field trials as tolerant to waterlogging stress (van Ginkel *et al.*, 1992) and were kindly provided by CIMMYT/EU Eastern Africa Wheat Program. Ten seeds of each genotype were planted to two pots in each replication on the 7th September 1998, covered slightly with thin-layer of loose soil and thinned to four seedlings after full emergence.

All genotypes were exposed to three waterlogging treatments: 1) a control without waterlogging or free drainage (FD) where seedlings were grown in the pots allowed to drain freely; 2) transient waterlogging (TW), seedlings were waterlogged for seven days followed by seven days free drainage in 2-wk cycles for a total of seven weeks; and 3) continuous waterlogging (CW), seedlings were kept permanently waterlogged for seven weeks. When the seedlings reached the 3-4 leaf stage (i.e., 14-day old seedlings), the pots of the waterlogging treatments were placed into a larger six liter non-perforated polyethylene pots. Waterlogging with tap water was then initiated and the level was maintained at 2-3 cm above the soil surface by watering daily throughout the treatment period.

The experiment was designed with four replications as a split plot with waterlogging treatments as main plots and genotypes as subplots. For the duration of the experiment, N solution was applied to every pot at a rate of 0.5-mg N nutrient as NH_4NO_3 at 2-wk intervals to avoid leaf chlorosis, which might be induced by N-deficiency. Greenhouse temperatures were maintained at 15 ^{O}C minimum and 25 ^{O}C maximum. At flowering, all the plants from one pot from each treatment were cut at soil surface, thoroughly washed in distilled water, oven-dried at 60 ^{O}C for 72 hrs, the dry biomass was weighed and then ground to pass through a 1-mm sieve for nutrient analysis. At maturity, all the plants from another pot were cut at 20 cm above the soil surface to avoid possibly contaminated lower plant parts, oven-dried at 60 ^{O}C for 48 hrs, the dry biomass was hand-threshed and then separated into straw and grain. Both straw and grain were ground to pass through a 1-mm sieve for nutrient analysis.

Determination of soil pH and redox potential:

Soil pH and redox potential readings were determined after 3-and 6-wk of waterlogging. An average of four readings from replicate pots was taken for each of the three waterlogging treatments using an appropriate platinum electrode. Measurements were made by inserting the electrode directly into the soil to a depth of 10 cm below the soil surface.

Plant analyses:

Plant mineral nutrient concentrations were determined for the whole-plant biomass at anthesis, and straw and grain at maturity for each genotype. Sub-samples of 2-g were dry-ashed at 550 ^{O}C, digested in nitric acid on a hot sand-bath, dissolved in diluted HNO_3, filtered into a volumetric flask and made to volume. The concentration of Cu, Zn and K were determined after proper dilution by Atomic Absorption Spectrometry. P was determined colorimetrically using the ammonium vanadate-molybdate method. Nutrient-uptake was calculated by multiplying each nutrient concentration value with their respective biomass, straw or grain masses.

Statistical analyses:
All measured parameters were subjected to appropriate analysis of variance using MSTAT-C micro-software. The data on soil redox potential and pH values as well as plant response measurements in the foliar application trial were analyzed as a randomized complete block design while all other data were analyzed as a split plot design. Differences among significant treatment means were separated using least significant differences (LSD) at $P \leq 0.05$.

RESULTS AND DISSCUSSION

Soil redox potential (Eh) and pH:
The effects of waterlogging on the soil Eh and pH readings after 3- and 6-wk of waterlogging are shown in Table 1. Soil Eh was greatly lowered by waterlogging. For both readings, CW gave significantly lower Eh-values than TW, which in turn gave significantly lower values than FD soils. The drop in Eh was much higher after 6-wk compared to 3-wk. It is generally accepted that an adequate O_2 supply to the root zone environment is essential for optimum plant growth and nutrient uptake. Oxygen is generally considered deficit around 350 mV at pH 7 on the Eh scale (Armstrong, 1979, 1982; Krizek, 1982; Laanbroek, 1990; Ponnamperuma, 1984). In our study, the Eh-values of the waterlogged soils, especially in CW soils, remained much lower than 350 mV (Table 1), suggesting that root zone oxygenation was significantly depressed by waterlogging which is in agreement with results reported by Davies and Chillman (1988), Musgrave (1992) and Thomson *et al.* (1992). Waterlogging reduced soil pH values at both readings in a similar manner as for Eh. Compared to the FD-treatment, pH values were reduced respectively by 0.23 and 0.59 units under TW- and CW- treatments after 3-wk and by 0.23 and 0.49 units after 6-wk. Increased concentrations of CO_2, an anaerobic metabolic product, and reduced mineral nutrients in waterlogged soil (Grable, 1966; Laanbroek, 1990) could probably contribute towards reducing pH-values under waterlogging.

Grain yield and biomass:
Soil waterlogging markedly reduced the growth of all the wheat genotypes (Table 2). Wheat genotypes obviously differed in their response to the waterlogging treatments and there was a significant waterlogging x genotype interaction for all plant parameters considered. Increased waterlogging severity caused a greater reduction of vegetative dry biomass, straw and grain yields for the sensitive Et-13, K6290-bulk genotypes and also for the tolerant genotype Vee/Myna and Ducula. Of the susceptible genotypes, Et-13 appeared to be more sensitive to continuous waterlogging and K6290-bulk to transient waterlogging treatment. Vee/Myna and Ducula were the most tolerant genotypes to waterlogging as shown by their better yielding ability than the other three genotypes. In a field study in Mexico, Ginkel *et al.* (1992) have previously identified these genotypes as tolerant to extended waterlogging stress. Davies and Hillman (1988) also reported differential biomass and yield response of tetraploid and hexaploid wheat populations to waterlogging stress.

Copper and zinc concentrations and uptake:
A significant waterlogging x genotype interaction was detected for the Zn and Cu concentration and uptake by grains (Tables 5 and 6). Grain Zn concentration and uptake, and Cu uptake reduced significantly for all genotypes as waterlogging severity increased, to a greater extent for the sensitive ET-13 and K6290-bulk. Cu concentration slightly increased, although not significantly, for all genotypes in the TW treatment except for ET-13. Huang *et al.* (1995) also reported a greater reduction in shoot Zn concentration for sensitive genotypes than for tolerant genotypes when waterlogged. Waterlogging caused a significant decrease in

all the Zn concentration and uptake parameters (Tables 3 and 4). Concentration and uptake values were the highest for FD, intermediate for TW and lowest for the CW treatments for all parameters. Decreasing Zn concentrations due to waterlogging was reported in wheat (Sharma and Swarup, 1988) and sorghum (Maranville *et al.*, 1986). Cu concentration in grain and uptake by both whole plant and grain were significantly decreased by waterlogging (Tables 3 and 4). Maranville *et al.* (1986) also reported a reduction in Cu concentration in sorghum at booting stage by more than 50% in response to waterlogging for several genotypes studied. Bjerre and Schierup (1985) reported significantly reduced plant Cu and Zn uptakes in waterlogged oats. A significant difference among genotypes was detected in grain Cu concentration and its uptake by the whole plant. The Zn concentration in the whole plant, straw and grains and its uptake by grain differed significantly among genotypes (Tables 3 and 4). Tolerant genotypes had significantly higher concentrations and uptake of Zn. Significant variations among genotypes in Cu- and Zn concentrations were reported in waterlogged sorghum (Maranville *et al.* 1986). In comparison with the nutrient sufficiency values previously published (Bergmann, 1992; Melsted *et al.*, 1969), the average concentrations of both Zn and Cu in waterlogged plants dropped below the 'critical' level of 0.50 and 1.50%, respectively, indicating that the Zn and Cu nutrient deficiencies were high in waterlogged plants. Uptake and metabolism of Zn is disturbed by high concentrations of P in the soil, especially when accompanied by high pH values and high clay and organic matter contents of the soil (Bergmann, 1992). The experimental soil used in this study had high organic matter (3.12%) and clay (46%) content; the pH values (Table 1) during experimental period remained well within the range (6.5-8.0) reported to cause Zn deficiency (Bergmann, 1992). The low Zn concentrations and uptake observed under waterlogging in this experiment (Tables 3 and 4) could partly also be attributed to an increase in P-concentration in soil (Phillips, 1998) which exacerbates soil Zn deficiency by enhancing bonding of Zn to oxides and hydroxides of Fe (Loneragan *et al.*, 1979) and to free organic oxides and bicarbonates (Fornco *et al.*, 1975) in waterlogged soils.

Phosphorus concentration and uptake:

The effect of waterlogging on grain P concentration and whole plant P uptake depended on wheat genotypes (Table 6 and 7). Grain P concentration significantly decreased in Et-13, K6290-bulk and PRL/Sara than in other genotypes in response to waterlogging, especially for the CW treatment. Whole plant P uptake significantly decreased for all genotypes as severity in waterlogging increased. The reduction was greater for ET-13, K6290-bulk and PRL/Sara than for the other genotypes. Huang *et al.* (1995) reported significant differences in shoot and root P concentration between sensitive and tolerant wheat genotypes in response to waterlogging. Whole plant, straw and grain P-concentrations as well as straw P uptake were significantly different among the wheat genotypes studied (Tables 3 and 4). P uptake by and concentration in the whole plant, straw or grain were greater for one or more of the tolerant genotypes than for the more sensitive ET-13 or K6290-bulk. The P-concentrations in the whole plant, straw, grain, and uptake by the whole plant and grain were significantly affected by waterlogging (Tables 3 and 4). Concentration and uptake parameters of P significantly decreased with increased waterlogging stress. When compared with 'critical' and sufficiency P nutrient levels on wheat, P concentration fell well below the 'critical' value of 0.30% reported by Melsted *et al.* (1969), indicating that waterlogged plants were P deficient. Similar results were also reported for waterlogged wheat (Sharma and Swarup, 1988; Steiger and Feller, 1994), barley (Leyshon and Sheard, 1974) and sorghum (Maranville *et al.*, 1986). The decline of P concentration observed in the waterlogged whole plants and grains (Table 3) could suggest that P absorption and transportation under waterlogging condition were

significantly suppressed by an O_2 deficiency due to impaired root functioning (Trought and Drew, 1980a and b) and lack of energy for ion uptake (Barrett-Lennard *et al.*, 1990).

Potassium concentrations and uptake:

The effect of waterlogging on the uptake and concentration parameters of K (Tables 5 and 6) depended on the wheat genotypes studied. Straw K concentration declined progressively with increased waterlogging severity for all genotypes except for PRL/Sara and Ducula for which the concentration was slightly increased for the TW treatment. Increasing severity in waterlogging led to lower K uptake for the sensitive ET-13 and K6290-bulk than for other genotypes. Huang *et al.* (1995) also reported lower stem K concentration for sensitive than for tolerant genotypes in response to waterlogging. Trought and Drew (1980a and b) ascribed low nutrient uptake and transportation through waterlogged roots as the cause for reduced K accumulation in plants. All parameters of K concentration and -uptake (except whole plant K concentration and straw K uptake) were significantly different among wheat genotypes (Tables 3 and 4). Waterlogging significantly affected all uptake and concentration parameters of K (Tables 3 and 4). K concentration and uptake were significantly decreased as waterlogging severity increased. Whole plant K concentration, measured at anthesis for waterlogged plants, were also lower than the 'critical' value of 1.80% reported on wheat (Melsted *et al.*, 1969). Hence, waterlogged plants in this study were deficient in K, which is in agreement with previous reports on wheat (Huang *et al.*, 1995; Sharma and Swarup, 1988; Stieger and Feller, 1994; Trought and Drew, 1980a and b), barley (Drew and Sisworo, 1979; Leyshon and Sheard, 1974), and on sorghum (Maranville *et al.*, 1986).

CONCLUSIONS

Waterlogging treatments significantly reduced vegetative dry biomass, straw and grain yields for all genotypes, but to a greater extent for the sensitive ET-13 and K6290-bulk. Root zone oxygenation was significantly depressed by the waterlogging treatments as indicated by lower redox potentials. Nutrient concentration and uptake of wheat under different waterlogging regimes differed among genotypes. The sensitive genotypes accumulated less Cu, Zn, K and P than the tolerant genotypes under waterlogged soil conditions. Concentrations of all nutrients except Cu appeared to be lower than the 'critical' values previously reported for wheat. The results indicated that the damaging effects of waterlogging on wheat could be attributed to the decreasing nutrient uptakes due to O_2 deficiency in the root zone, particularly P and Zn deficiencies. Zn deficiency is most common in cool and wet highland Vertisols with high montmorillonite clay, pH values, and phosphate and organic matter content. In a breeding program aimed at improving waterlogging tolerance in wheat, selection of genotypes with greater ability to overcome the waterlogging–induced nutrient deficiency, particularly P and Zn deficiency could improve wheat productivity in waterlogged soils.

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Table 1. Mean effects of waterlogging on soil pH and redox potential, 1998/99.

Waterlogging	Redox potential (mV)		Soil pH	
	3-wk	6-wk	3-wk	6-wk
Free drainage	394a[+]	410a	7.15a	7.20a
Transient	271b	163b	6.92b	6.92b
Continuous	135c	10c	6.61c	6.71b
Prob.	***	***	***	***
LSD(0.05)	21	37	0.11	0.25
Mean	266.67	194.33	6.89	6.94
C.V.(%)	7.58	17.73	1.45	3.27

, * Represent significance at 0.01 and 0.001 probability level.
[+]Means followed by the same latter are not significantly different at 0.05 probability level.

Table 2. Mean effects of waterlogging x genotype interaction on whole plant dry biomass at anthesis, and final straw and grain yield of wheat, 1998/99.

Genotype	Whole plant Dry biomass			Straw yield			Grain yield		
	FD*	TW	CW	FD	TW	CW	FD	TW	CW
	g/plot								
ET-13	37.22	33.32	16.06	35.24	28.62	19.76	30.08	25.60	13.05
K6290-bulk	37.13	29.88	24.41	30.51	24.55	22.82	26.85	17.69	15.00.
Vee/Myna	34.38	27.74	27.08	28.61	23.96	23.45	26.46	22.95	19.67
PRL/Sara	32.14	21.24	15.70	31.97	24.46	21.45	23.50	20.85	14.38
Ducula	29.67	28.47	19.15	27.71	23.00.	21.99	23.59	21.86	19.37
LSD(0.05)		4.50			3.11			2.908	

*FD-Freely drained control; TW-transient waterlogging; CW-continuous waterlogging

Table 3. Mean Cu, Zn, P and K concentrations and statistical significance of treatment effects in bread wheat genotypes, 1998/99.

Factor	Whole plant biomass at anthesis				Straw at harvest				Grain at harvest			
	Cu (mg/kg D.M.)	Zn	K (mg/g D.M.)	P (%)	Cu (mg/kg D.M.)	Zn	K (mg/g D.M.)	P (%)	Cu (mg/kg D.M.)	Zn	K (mg/g D. M.)	P (%)
Waterlogging (W)	**NS**	***	***	***	**Ns**	*	***	*	**	*	*	**
Control	5.5	14.8a	21.15a	0.162a	2.15	6.28a	19.25a	0.028b	6.52a	21.5a	2.65a	0.37a
Transient	5.5	8.0b	15.09b	0.132b	2.75	4.22b	18.79a	0.034b	6.40a	20.6a	2.46ab	0.31b
Continuous	4.6	6.8b	12.75c	0.106c	1.95	4.22b	13.70b	0.052a	3.97b	16.8b	2.32b	0.30c
LSD(0.05)	--	1.75	1.40	0.016	--	1.57	1.57	0.014	1.32	3.34	0.24	0.040
Genotype (G)	**NS**	***	**Ns**	**	**Ns**	*	***	**	**	***	***	***
ET-13	5.3	9.0b	16.96	0.126bc	2.13	4.71b	15.52c	0.038b	4.46b	15.5c	2.15c	0.29b
K6290-Bulk	5.2	9.5b	15.20	0.110c	2.50	4.83b	16.75bc	0.032b	6.17a	19.1b	2.64a	0.36a
Vee/Myna	5.2	8.5b	15.95	0.136ab	2.42	4.58b	19.36a	0.034b	5.46a	17.8bc	2.46b	0.29b
PRL/Sara	5.2	11.2a	16.64	0.146ab	2.13	4.50b	16.68bc	0.036b	5.96a	22.5a	2.32b	0.36a
Ducula	5.3	11.1a	16.91	0.152a	2.21	5.92a	17.91ab	0.048a	6.13a	22.6a	2.80a	0.34a
LSD(0.05)	--	1.55	--	0.020	--	1.00	1.71	0.008	0.88	2.38	0.17	0.036
W x G	**NS**	**NS**	**Ns**	**Ns**	**Ns**	**Ns**	**	**Ns**	*	*	**Ns**	***
C.V.(%)	17.7	19.06	13.97	17.55	22.73	24.63	11.97	25.95	18.78	14.75	8.06	13.00

Table 4. Statistical significance of treatment effects and mean Cu, Zn, K and P uptake by bread wheat genotypes, 1998/99.

Factor	Whole plant biomass (mg/pot) at anthesis				Straw uptake (mg/pot) at harvest				Grain uptake (mg/pot) at harvest			
	Cu	Zn	P	K	Cu	Zn	P	K	Cu	Zn	P	K
Waterlogging (W)	**	***	***	***	Ns	***	Ns	***	**	***	***	***
Control	0.19a	0.50a	55.2a	716.76a	0.07	0.19a	8.4	589.20a	0.16a	0.54a	9.83a	67.78a
Transient	0.15a	0.22b	37.0b	418.47b	0.07	0.10b	8.2	464.06b	0.13b	0.40b	6.73a	54.20b
Continuous	0.09b	0.13c	21.1c	256.00c	0.04	0.09b	11.4	301.26c	0.07c	0.29c	4.98b	38.02c
LSD(0.05)	0.047	0.033	7.4	5.19	-----	0.033	---	6.22	0.04	0.06	1.8	2.68
Genotype (G)	*	Ns	Ns	***	Ns	Ns	**	Ns	Ns	***	Ns	***
ET-13	0.16a	0.28	38.8	507.46a	0.06	0.13	9.8ab	451.66	0.10	0.35c	6.99	49.92cd
K6290-Bulk	0.16a	0.31	35.4	476.82c	0.07	0.13	8.2b	442.51	0.12	0.39bc	7.18	53.18bc
Vee/Myna	0.16a	0.26	40.6	484.55b	0.06	0.12	8.4b	494.79	0.12	0.41b	6.85	56.95ab
PRL/Sara	0.12b	0.28	34.2	404.59e	0.06	0.12	8.6b	433.08	0.12	0.42b	7.11	45.60d
Ducula	0.14ab	0.30	39.8	445.30d	0.05	0.15	11.4a	435.48	0.13	0.49a	7.71	61.02a
LSD(0.05)	0.025	----	-----	4.36	-----	----	2.0	--------	-----	0.05	------	5.13
W x G	Ns	Ns	**	*	Ns	Ns	Ns	**	*	***	**	***
C.V.(%)	21.21	18.87	17.01	11.35	25.16	28.52	24.83	12.46	23.71	13.48	12.87	11.62

Table 5. Mean effects of waterlogging x genotype interaction on Cu, Zn, P and K nutrient concentration in bread wheat genotypes, 1998/99.

Genotype	Grain									Straw		
	Cu			Zn			P			K		
	FD*	TW	CW	FD	TW	CW	FD	TW	CW	FD	TW	CW
	mg/g D.M.						(%)			mg/g D.M.		
ET-13	5.3	4.5	3.6	17	17	13	0.42	0.24	0.22	18.40	16.71	11.45
K6290-bulk	6.4	7.0	5.1	23	17	17	0.40	0.34	0.34	21.39	16.46	12.39
Vee/Myna	5.5	6.5	4.4	20	18	15	0.32	0.28	0.28	21.79	20.51	15.79
PRL/Sara	7.0	7.5	3.4	21	18	19	0.40	0.34	0.34	16.00	19.44	14.60
Ducula	7.0	8.0	3.4	24	23	20	0.38	0.32	0.32	18.66	20.80	14.26
LSD(0.05)		1.5			4.1			0.06			2.96	

*FD-freely drained control; TW-transient waterlogging; CW-continuous waterlogging.

Table 6. Mean effects of waterlogging x genotype interaction on the P, K, Cu, and Zn nutrient uptake by bread wheat genotypes, 1998/99.

Genotype	Whole plant biomass at anthesis						Straw			Grain											
	P			K			K			Cu			Zn			P			K		
	FD*	TW	CW	FD	TW	CW	FD	TW	CW	FD	TW	CW	FD	TW	CW	FD	TW	CW	FD	TW	CW
	mg/pot																				
ET-13	60.4	41.6	14.4	797	486	240	648	479	228	0.16	0.11	0.05	0.52	0.44	0.17	12.03	6.12	2.83	71	52	27
K6290-bulk	56.6	31.6	18.0	727	420	283	643	404	280	0.17	0.12	0.08	0.61	0.30	0.26	10.54	6.03	5.11	76	47	36
Vee/Myna	53.4	40.0	28.2	714	423	316	625	491	369	0.14	0.13	0.09	0.52	0.41	0.30	8.33	6.45	5.77	69	58	45
PRL/Sara	54.6	27.2	20.4	702	326	189	513	472	315	0.16	0.15	0.06	0.49	0.39	0.28	9.38	7.09	4.87	57	45	34
Ducula	50.4	44.4	24.8	647	441	251	517	475	314	0.16	0.16	0.07	0.58	0.48	0.43	8.86	7.96	6.30	67	69	49
LSD(0.05)		4.6			7.55			8.07			0.04			0.08			1.06			8.9	

*FD-freely drained control; TW-transient waterlogging; CW-continuous waterlogging.

EFFECT OF CROP ROTATION AND FERTILIZER APPLICATION ON WHEAT YIELD PERFORMANCE ACROSS FIVE YEARS AT TWO LOCATIONS IN SOUTH-EASTERN ETHIOPIA

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ABSTRACT

A crop rotation experiment was initiated at the Asasa and Kulumsa locations in 1992. At both locations, the rotation crops used were faba bean (*Vicia faba*), rapeseed (*Brassica carinata*), and barley (*Hordeum vulgare*) in 2- and 3-course rotations with wheat (*Triticum aestivum*); continuous wheat was included as a control treatment. Two rates of nitrogen (30 and 60 kg N ha^{-1}) and two rates of phosphorus (0 and 20 kg P ha^{-1}) in factorial combination were applied as subplots within rotations during the period from 1995 to 1999. The combined analysis of the results generated at each location during 1995 to 1999 showed that rotation had a significant effect on wheat grain yield and most yield components of wheat at both Kulumsa and Asasa. At both locations, rotation with faba bean had a marked effect on the grain yield of wheat. Wheat following faba bean in a 2-course rotation (FbW) and first wheat after faba bean in a 3-course rotation (FbWW) significantly outyielded all other treatments at Kulumsa. At Asasa, first wheat after rapeseed in a 2-course rotation (RpW) did not differ from the faba bean treatments (i.e., FbW, FbWW, FbWW). The treatments FbW and FbWW resulted in grain yield increments of 1.37 and 1.30 t ha^{-1}, respectively, relative to the continuous wheat treatment at Kulumsa, whereas at Asasa grain yield increases were 0.86 and 1.05 t ha^{-1}, respectively. At both locations, there was no significant difference between the yield of wheat in barley rotations and continuous wheat. Crop rotation treatments exerted significant effects on wheat grain yield response to applied N and P nutrients: rotation with faba bean minimized wheat response to fertilizer N; crop rotation, in general, tended to enhance wheat response to applied P.

INTRODUCTION

Sustainable agriculture has been defined as "the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources" (TAC, 1988). The maintenance of long-term agricultural productivity depends on a number of biotic and abiotic factors, all of which are dynamic in response to human intervention. Conservation tillage and crop rotation are considered to be the major means of maintaining agricultural productivity globally (Lal, 1989).

Practical rotation options for cropping systems in wheat producing zones have been considered in only a few cases in sub-Saharan Africa (SSA). Most of these studies have

focused on the short-term agronomic benefits from break or precursor crops for wheat production (Hailu *et al.,* 1989). One eight year rotational study in Ethiopia provided extensive information on the impact of various cropping sequences on wheat grain yield (Amanuel and Tanner, 1991), but this particular set of trials contained several methodological flaws (Amanuel *et al.*, 1994).

Fertilizer rates have been recommended for wheat production in SSA without considering the sustainability of continuous fertilizer application. In Ethiopia, high rates of nitrogen (N) applied to bread wheat in single-season on-farm fertilizer trials had repercussions on soil pH levels, severity of wheat foliar disease, and weed incidence and competition (Tanner *et al.,* 1993). However, there are no reports available on the long-term effects of repeated N and phosphorus (P) application at the rates recommended for wheat production.

In the peasant farming systems of south-eastern Ethiopia, cereals predominate, often occupying over 80% of the total cropped land each season (Chilot *et al.*, 1992). In the highland zones, bread wheat and barley are the most common cereals in production, while faba bean and rapeseed are the most common grain legume and oilseed crops, respectively.

The high proportion of wheat and barley in the highland cropping systems satisfies the short-term subsistence objectives of peasant farmers, but may prove detrimental in the long-term due to the absence of the inherent advantages of crop rotational systems. Crop rotation could be extremely beneficial in the peasant farming sector for several reasons: N fixation by legumes (Hargrove *et al.*, 1983); the interruption of weed (Heenan *et al.*, 1990), disease and insect cycles by dicotyledonous crops; crop diversification (Zentner and Campbell, 1988); improvement in soil tilth and a concomitant reduction in rainfall runoff and erosion (Higgs *et al.*, 1990).

Several short-term studies in the Ethiopian highlands have examined the beneficial effects of break crops on wheat production. In one study, a faba bean break crop increased wheat grain yield by 1100 kg ha^{-1}, or 69%, cf. the yield of second year continuous wheat (Hailu *et al.*, 1989); in a second study, faba bean increased wheat yield by 1000 kg ha^{-1}, or 44%, cf. the yield of continuous wheat (Asefa *et al.*, 1992). However, no studies have previously considered the long-term effects of diverse cropping sequences on the Ethiopian cropping environment.

This paper presents a combined analysis of wheat agronomic data generated during the period from 1995 to 1999 in an ongoing study conducted at two locations in a major bread wheat production zone in south-eastern Ethiopia. Previous reports have summarized results obtained during the first four years of this trial regarding effects of rotation on weed populations (Amanuel *et al.*, 1996a), soil nitrate and compaction characteristics (Amanuel *et al.*, 1996b), crop yield components (Asefa *et al.*, 1997), and soil-borne pathogen incidence (Tezera *et al.*, 1996). The objective of this paper is, therefore, to evaluate the long-term effects of alternate crop rotation systems on wheat productivity, and on wheat response to inorganic fertilizer.

MATERIALS AND METHODS

The rotation experiment was initiated during 1992 at the Kulumsa (8°02'N and 39°10'E) and Asasa (7°08'N and 39°13'E) research sites in Arsi Region of Ethiopia; the station soils are classified as an intergrade (between an eutric Nitosol and a luvic Phaeozem) and an eutric Nitosol, respectively. The soil clay content is approximately 45% at Kulumsa and 35% at

Asasa. The average monthly mean minimum temperatures during the annual growing season are 10.6 and 6.7°C, and the corresponding average monthly mean maximum temperatures are 22.1 and 22.7°C, respectively. Total annual precipitation is 824 and 665 mm, and that received during the June-November growing season is 504 and 472 mm, respectively (1970-95 means). The stations are situated at altitudes of 2200 and 2360 m a.s.l., respectively. The experimental sites used for the rotation trials had been sown to unfertilized wheat crops in 1991.

The trial incorporates three fundamental design principles consistently stressed in the statistical literature on multi-rotation experiments (Patterson, 1965; Preece, 1986; Cady, 1991):

- Each phase of a specific rotation is present in the experiment every year to avoid assessing the effects of the rotational crops under differing seasonal conditions (i.e., confounding treatment and year effects). A three year cycle requires three plots in each replication to include all three phases of the rotation, while a two year cycle occurs in two phases each year.
- Randomization is essential to avoid anomalies from systematic assignment of treatments to field plots, and is fundamental to the validity of statistical analyses.
- Replication is required to estimate experimental error and to minimize the magnitude of the standard error of treatment means.

The experiment was laid out in a split-plot design with crop rotations as main plots and fertilizer levels as subplots. The crop rotations are wheat-based, and reflect the predominant crops in the surrounding farming system: faba bean, rapeseed and barley. Treatments 1 to 15 (Table 1) comprise all phases of wheat in two and three year rotations with the three break crops, while treatment 20 consists of continuous wheat. Treatment pairs 16 and 17 and 18 and 19 comprise a partial sampling of all potential phases of complex six and four year rotations, respectively. The four fertilizer levels used during the period 1995-1999 were the factorial combinations of 30 and 60 kg N ha^{-1} with 0 and 20 kg P ha^{-1}. The four fertilizer combinations were maintained as fixed subplots over the duration of the trial. Urea and triple superphosphate are the sources of N and P, respectively. The trial is laid out in three replications, and the area of each main plot is 100 m^2 with each fertilizer subplot having an area of 25 m^2.

Tillage for this trial is based on the local ox-plough; crop protection practices simulate farmer practices (i.e., hand weeding); varietal selection is optimal for each crop, and open to change over the trial duration. The recommended varieties used during the 1995-1999 period for the various crop species were: for bread wheat, HAR 1685 (Kubsa); for barley, ARDU 12-60B; for faba bean, CS20DK; for rapeseed, Yellow Dodola. The seed rates used were 150 kg ha^{-1} for bread wheat, 200 kg ha^{-1} for faba bean, 15 kg ha^{-1} for rapeseed, and 130 kg ha^{-1} for barley.

Pre-weighed amounts of seed and fertilizer were broadcast applied on the soil surface of the appropriate plots after tillage by ox-plough, and were subsequently incorporated, in the traditional Ethiopian practice, by one pass of the ox-plough. Sowing dates followed farmers' practice at both sites (i.e., sowing from mid June to early July as soon as sufficient rain has been received to saturate the surface soil layer).

Each year, at crop maturity, a net plot of 9 m^2 from each subplot was harvested by sickle at ground level for grain and biomass yield determination. Grain moisture contents were determined and yields adjusted to a 12.5% moisture basis for wheat.

Table 1. Treatments included in the crop rotation experiment at Kulumsa and Asasa.

Treat.	Rotation-Phase	1995	1996	1997	1998	1999
1	1-1	W*	Fb	W	Fb	W
2	1-2	Fb	W	Fb	W	Fb
3	2-1	W	Ba	W	Ba	W
4	2-2	Ba	W	Ba	W	Ba
5	3-1	W	Rp	W	Rp	W
6	3-2	Rp	W	R	W	R
7	4-1	Rp	W	W	Rp	W
8	4-2	W	W	Rp	W	W
9	4-3	W	Rp	W	W	Rp
10	5-1	Fb	W	W	Fb	W
11	5-2	W	W	Fb	W	W
12	5-3	W	Fb	W	W	Fb
13	6-1	Ba	W	W	Ba	W
14	6-2	W	W	Ba	W	W
15	6-3	W	Ba	W	W	Ba
16	7-1	Rp	W	W	Fb	W
17	7-2	Fb	W	W	Rp	W
18	8-1	W	Fb	W	Rp	W
19	8-2	W	Rp	W	Fb	W
20	-	W	W	W	W	W

* W = wheat, Ba = barley, Fb = faba bean, Rp = rapeseed.

In the current report, data generated during 1995-1999 from wheat in 2- and 3-course rotations and the continuous wheat treatment are considered. Combined analysis of data was conducted across years for each location using ANOVA. Year was treated as a main factor, and rotation and fertilizer as sub- and sub-sub-factors, respectively.

RESULTS AND DISCUSSION

Rotation Effects on Wheat Grain Yield

The results of the ANOVA of the rotation experiments conducted at Kulumsa and Asasa combined over the period 1995 to 1999 are presented in Tables 2 and 3. The results revealed that rotation had significant effects on wheat grain yield (GY) and the majority of yield components at both locations. Rotation by year interaction effect was significant for GY and some wheat parameters. Differences among rotations were distinct at both locations. Dicot precursor crops resulted in higher GYs of subsequent wheat crops relative to the continuous cereal cropping systems (Tables 4 and 5). At both locations, faba bean had the most dramatic effect on the GY of a succeeding wheat crop.

At Kulumsa, wheat after faba bean in a 2-course rotation (FbW) and first wheat after faba bean in a 3-course rotation (FbWW) significantly outyielded all other rotation treatments included in the current study (Table 4). The superior performance of these two treatments suggests that the growth and development of the first wheat following a precursor faba bean crop is probably benefiting from atmospheric N_2 fixed by faba bean and available soil mineral N spared by the legume. The top yielding faba bean treatments, FbW and FbWW, gave GY increments of 1.37 and 1.30 t ha^{-1}, respectively, in comparison to the continuous wheat treatment at Kulumsa. Second wheat after faba bean (FbWW) produced a GY similar to the rapeseed precursor treatments (i.e., RpW, RpWW and RpWW). FbWW, RpW and RpWW exhibited equal performance producing additional GY of 0.62, 0.67 and 0.64 t ha^{-1}, respectively, relative to continuous wheat. Although oilseed rape is not an N_2 fixing crop, such GY increases after a rapeseed precursor presumably reflect other crop rotation advantages such as improved soil structure and reduced incidence of diseases and weeds (Kirkegaard *et al.*, 1994). Regarding soil structure improvement, an earlier report revealed that penetrometer resistance (PR) was reduced in rapeseed plots relative to faba bean plots (Amanuel *et al.*, 1996b). In the current study, there was no difference among the rapeseed treatments; however, RpWW produced the lowest GY, and as a result was not significantly different in GY from wheat in the barley rotations (i.e., BaW, BaWW and BaWW) or continuous wheat (Table 4).

At Asasa, wheat GY responded to rotation treatments in a similar fashion to GY at Kulumsa. The faba bean treatments FbW and FbWW were the highest yielding treatments at Asasa (Table 5). The GY increments of these treatments cf. continuous wheat were 0.86 and 1.05 t ha^{-1}, respectively. The GY performance of the faba bean treatments at Asasa followed the order FbWW > FbWW, while FbW was intermediate. The GY of RpW was higher than that of RpWW, and was comparable to the faba bean treatments, giving an additional GY of 0.6 t ha^{-1} relative to continuous wheat. The GYs of FbW, FbWW, RpW and RpWW were not significantly different from each other. As at Kulumsa, the GYs of wheat following a barley precursor and continuous wheat were not significantly different from each other.

Rotation Effects on Wheat Yield Components

The results of the ANOVA for rotation effects on wheat yield components are presented in Tables 2 and 3. Among the wheat parameters, plant height, number of spikes m^{-2} and number of grains per spike were significantly influenced by rotation systems at both locations. Wheat seedlings m^{-2}, thousand kernel weight (TKW), and harvest index (HI) were significantly influenced by rotation at one location only.

Wheat plant height (PH) significantly increased in faba bean rotations at both locations. FbW and FbWW exhibited an equal height increase of 5 cm at Kulumsa and 6 cm at Asasa relative to continuous wheat (Tables 4 and 5). The continuous cereal rotations resulted in relatively shorter wheat plants, reflecting the positive contribution of faba bean as an N source for the enhanced growth of the wheat crop.

The maximum number of spikes m^{-2} occurred in FbW and FbWW plots at both Kulumsa and Asasa, indicating that seedlings and tillers developing during the early vegetative stage were more vigorous in the first wheat following faba bean, presumably because of a surplus N supply from different sources (i.e., fertilizer, fixed N, soil). Ultimately, these treatments also resulted in significantly more grains per spike. Wheat following rapeseed and in continuous cereal rotations did not differ in the number of grains per spike.

HIs of the semi-dwarf wheat cultivar used in this experiment were generally high at Kulumsa, ranging from 43.3% for RpWW to 45.1% for FbWW. At Asasa, the highest HI, 39.8%, and the lowest HI, 36.8%, were recorded on BaW and the continuous wheat, respectively.

TKW was not significantly affected by treatments at Asasa. However, at Kulumsa, FbW exhibited a higher TKW than FbWW, RpWW, BaWW and continuous wheat (Table 4).

Rotation x Nutrient Interaction Effects

Applied N and P exerted a significant influence on wheat GY and some yield components at Asasa (Table 3). The higher rate of 60 kg N ha^{-1} enhanced GY, PH and spikes m^{-2}, but reduced HI and TKW relative to the lower N rate (30 kg ha^{-1}). Application of 20 kg P ha^{-1} significantly increased PH, spikes m^{-2}, TKW and GY.

The effect of N and P was limited to certain yield components at Kulumsa (Table 2). GY, PH, spikes m^{-2} and grains $spike^{-1}$ increased significantly with the higher N rate. Applied P only increased PH and spikes m^{-2} significantly.

Rotation x N interaction was significant at Kulumsa for GY ($P<0.01$), PH ($P<0.1$) and HI ($P<0.1$); at Asasa, only PH ($P<0.01$), spikes m^{-2} ($P<0.05$) and GY ($P<0.01$) were influenced significantly by the interaction effect (Tables 2 and 3).

The response of wheat GY to an increased rate of N was generally low at Asasa relative to Kulumsa across all rotation treatments (Table 6). Increasing the applied N rate from 30 to 60 kg ha^{-1} did not result in significant yield increments at either location in the FbW and FbWW treatments, probably due to a high soil N level as a result of atmospheric N fixation by the preceding faba bean crop. In contrast, wheat GY increased in response to the additional 30 kg N ha^{-1} in FbWW at both locations, indicating that the first wheat crop following faba bean had partially depleted the soil N levels; particularly at Kulumsa, however, the GY response of FbWW to the higher N rate was markedly lower than the rapeseed and continuous cereal rotations. The relatively low response to N at Asasa may be explained by the lower rainfall received during the cropping cycle at this site; at Asasa, moisture stress during grain filling is commonly observed to be a yield limiting factor. At Kulumsa, the higher rate of N increased wheat GYs in rapeseed rotations (0.73-0.85 t ha^{-1}), barley rotations (0.55-0.85 t ha^{-1}) and in continuous wheat (0.62 t ha^{-1}). This indicates the need for higher N rates in continuous cereal production systems or in rotations lacking an N_2 fixing legume crop.

At Kulumsa, application of 20 kg P ha^{-1} increased GY by 0.65, 0.55, 0.38 and 0.27 t ha^{-1} in the RpW, RpWW, FbW and BaW treatments, respectively (Table 6). At Asasa, P application increased GY by 0.61, 0.58, 0.46, 0.42, 0.36, 0.33 and 0.32 t ha^{-1} in RpWW, FbW, BaW, FbWW, FbWW, BaWW and RpW, respectively. The preponderance of significant P responses in first crop wheat following the entire range of precursor crops, but not in continuous wheat, suggests that some aspect of crop rotation influences the P response. Presumably, the first crop wheat exhibits enhanced root health (Tezera *et al.*, 1996), and therefore benefits from the applied P nutrient.

The agronomic efficiency (AE) of an incremental 30 kg N ha^{-1} was non-significant at both locations for FbW and FbWW (Table 6). The highest AEs of 28.3, 28.3, 26.0, 24.3 and 22.0 kg grain per kg N applied were recorded in the RpWW, BaW, RpWW, RpW and BaWW

treatments, respectively, at Kulumsa. At Asasa, the AE for N was relatively low across all treatments; however, BaWW exhibited the highest AE of 20.3 kg grain per kg N at Asasa.

The AE of an incremental 20 kg P ha^{-1} was significant at Kulumsa for only four rotation treatments: 32.5 for RpW, 27.5 for RpWW, 19.0 for FbW and 13.5 for BaW (Table 6). In contrast, AE was significant for seven treatments at Asasa: the RpWW, FbW, BaW, FbWW, FbWW, BaWW and RpW treatments exhibited AEs of 30.5, 29.0, 23.0, 21.0, 18.0, 16.5 and 16.0 kg grain per kg applied P.

CONCLUSIONS

The long-term data set generated by this experiment revealed that the first wheat following a faba bean precursor crop either in a 2- or 3-course rotation consistently resulted in superior grain yields in both environments. A rapeseed precursor also resulted in significant grain yield increments in a succeeding wheat crop. The low yields obtained from the continuous cereal rotations at both locations indicate the need to encourage the adoption of appropriate crop rotations by peasant farmers in Ethiopia. In particular, the proportion of legumes should be increased in the currently cereal-dominated cropping systems. Crop rotation treatments exerted significant effects on wheat response to applied N and P nutrients: rotation with faba bean minimized wheat response to fertilizer N; crop rotation, in general, enhanced wheat response to applied P. The use of the N_2 fixing leguminous crop faba bean in rotation with wheat in the present experiment clearly demonstrated the importance of legume-cereal rotation systems in sustaining wheat production and reducing the consumption of costly imported inorganic N fertilizer.

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Table 2. Effects of crop rotation and fertilizer rate on grain yield (kg/ha) and yield components of wheat across five years at Kulumsa.

	SDPM (no.)	PH (cm)	SPM (no.)	HI (%)	TKW (g)	GPS (no.)	GY
Year (Y)	***	***	***	**	***	***	***
Rotation (R)	*	***	***	NS	***	***	***
Y x R	NS	**	**	NS	$P<0.1$	NS	**
Nitrogen (N)	$P<0.1$	*	***	NS	NS	***	**
Y x N	NS	**	NS	$P=0.1$	***	NS	***
R x N	NS	$P<0.1$	NS	$P<0.1$	NS	NS	**
Y x R x N	NS	NS	NS	NS	***	***	***
Phosphorus (P)	*	***	NS	NS	NS	*	$P<0.1$
Y x P	NS	NS	NS	***	***	NS	***
R x P	NS	NS	NS	NS	NS	*	**
Y x R x P	NS	**	NS	$P<0.1$	$P<0.1$	NS	*
N x P	NS	*	NS	NS	NS	NS	NS
Y x N x P	NS	NS	$P<0.1$	$P<0.1$	NS	NS	*
R x N x P	NS	NS	NS	NS	NS	NS	NS
Y x R x N x P	NS	NS	NS	NS	NS	NS	NS

$P<0.1$, *, **, ***, NS: Significant at the 10, 5, 1 and 0.1% levels and non-significant, respectively.
When Year x Factor interaction is significant ($P<0.05$), this interaction is used as the denominator in the F-test of significance for the respective factor.
SDPM = Seedlings per m^2; PH = Plant height; SPM = Spikes per m^2; HI = Harvest index; TKW = Thousand kernel weight; GPS = Grains per spike; GY = Grain yield.

Table 3. Effects of crop rotation and fertilizer rate on grain yield (kg/ha) and yield components of wheat across five years at Asasa.

	SDPM (no.)	PH (cm)	SPM (no.)	HI (%)	TKW (g)	GPS (no.)	GY
Year (Y)	**	***	***	***	***	**	***
Rotation (R)	NS	***	***	**	***	**	***
Y x R	NS	**	**	NS	NS	NS	**
Nitrogen (N)	NS	*	*	**	**	NS	*
Y x N	NS	***	***	NS	NS	**	***
R x N	NS	**	*	NS	NS	NS	**
Y x R x N	NS	NS	NS	$P<0.1$	NS	NS	NS
Phosphorus (P)	**	**	*	NS	*	$P<0.1$	**
Y x P	NS	*	NS	**	NS	NS	*
R x P	NS	NS	NS	NS	NS	NS	NS
Y x R x P	NS	NS	NS	NS	NS	NS	$P<0.1$
N x P	NS	NS	NS	NS	NS	NS	*
Y x N x P	NS	NS	NS	NS	NS	NS	NS
R x N x P	NS	NS	NS	NS	NS	NS	NS
Y x R x N x P	NS	NS	NS	NS	NS	NS	NS

See Table 2 for definitions and abbreviations.

Table 4. Wheat grain yield (kg/ha) and yield components as affected by crop rotation across five years at Kulumsa.

Cropping sequence	SDPM (no.)	PH (cm)	SPM (no.)	HI (%)	TKW (g)	GPS (no.)	GY
FbW	285 AB	86 A	381 A·	44.6	34.0 A	35.1 A	4500 A
FbWW	289 A	86 A	379 A	45.1	33.5 AB	35.6 A	4430 A
FbWW	267 BC	83 BC	347 BCD	43.6	32.3 BC	33.3 AB	3750 B
RpW	284 AB	83 BC	361 ABC	44.1	33.5 AB	31.9 BC	3800 B
RpWW	272 ABC	84 B	366 AB	43.3	33.3 AB	31.5 BC	3770 B
RpWW	260 C	82 CD	337 DE	43.5	32.4 BC	32.3 BC	3440 BC
BaW	266 BC	81 D	338 CDE	44.2	33.1 AB	30.2 C	3330 C
BaWW	261 C	82 CD	332 DE	43.7	33.0 AB	30.0 C	3250 C
BaWW	261 C	82 CD	323 E	44.2	32.5 BC	31.2 BC	3230 C
Cont. wheat	270 ABC	81 D	318 E	43.9	32.6 C	31.9 BC	3130 C
Mean	272	83	348	44.0	32.9	32.3	3660
C.V.(%)	17.4	3.4	13.2	8.6	6.8	17.3	10.9
LSD(0.05)	21	1.86	24	NS	1.4	2.4	389

See Table 2 for definitions and abbreviations.
Values in a column followed by the same letter(s) or by no letters are not significantly different at the 5% level of the LSD test.

Table 5. Wheat grain yield (kg/ha) and yield components as affected by crop rotation across five years at Asasa.

Cropping sequence	PH (cm)	SPM (no.)	HI (%)	TKW (g)	GPS (no.)	GY
FbW	90 A	449 A	37.5 AB	28.2	25.6 AB	3260 AB
FbWW	90 A	454 A	37.5 AB	28.2	27.2 A	3450 A
FbWW	87 BC	412 ABC	37.1 AB	27.7	24.6 BC	2780 BCD
RpW	88 AB	421 AB	38.6 AB	30.1	23.8 BCD	3000 ABC
RpWW	88 AB	399 BC	38.8 AB	29.5	24.7 BC	2870 BCD
RpWW	87 BC	383 BCD	37.0 AB	28.5	23.4 CD	2480 D
BaW	86 BCD	372 CD	37.9 AB	30.0	24.1 BCD	2630 CD
BaWW	85 CDE	370 CD	39.8 A	30.2	24.0 BCD	2620 CD
BaWW	83 E	352 D	37.8 AB	30.0	23.6 CD	2410 D
Cont. wheat	84 DE	379 BCD	36.8 B	28.0	22.7 D	2400 D
Mean	86.7	399	37.9	29.0	24.4	2790
C.V.(%)	3.8	14.8	9.7	10.4	19.8	14.5
LSD(0.05)	2.8	46	2.9	NS	1.9	491

See Table 2 for definitions and abbreviations.
Values in a column followed by the same letter(s) or by no letters are not significantly different at the 5% level of the LSD test.

Table 6. Wheat grain yield increment (kg/ha) and nutrient response (kg grain/kg nutrient) with increased rates of N and P application across five years at Kulumsa and Asasa.

Cropping sequence	Yield increment				Nutrient response			
	N[a]		P[b]		N[a]		P[b]	
	Kul	As	Kul	As	Kul	As	Kul	As
FbW	40	-60	380	580	NS	NS	19.0	29.0
FbWW	250	0	140	360	NS	NS	NS	18.0
FbWW	310	260	160	420	10.3	8.7	NS	21.0
RpW	730	240	650	320	24.3	8.0	32.5	16.0
RpWW	850	420	550	280	28.3	14.0	27.5	NS
RpWW	780	390	-30	610	26.0	13.0	NS	30.5
BaW	850	140	270	460	28.3	NS	13.5	23.0
BaWW	660	390	0	330	22.0	13.0	NS	16.5
BaWW	550	610	110	250	18.3	20.3	NS	NS
Cont. wheat	620	450	150	230	20.7	15.0	NS	NS
LSD(0.05)	306	205	254	309	-	-	-	-

[a] 60 vs. 30 kg N/ha/annum.
[b] 20 vs. 0 kg P/ha/annum.

EFFECTS OF TILLAGE AND CROPPING SEQUENCE PRACTICES ON WHEAT PRODUCTION OVER EIGHT YEARS ON A FARMER'S FIELD IN THE SOUTH-EASTERN HIGHLANDS OF ETHIOPIA

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ABSTRACT

Bread wheat (*Triticum aestivum*) yields are often low on peasant farmers' fields in Ethiopia due to the use of sub-optimal crop management practices. An on-farm crop management trial was initiated in 1992 in Arsi Zone in the south-eastern highlands of Ethiopia. The long-term trial examined the effects of tillage practice and cropping sequence on various parameters of bread wheat and the break crops faba bean (*Vicia faba),* rapeseed (*Brassica carinata*) and barley (*Hordeum vulgare*). A three year crop rotation, consisting of two consecutive crops of wheat following one crop of faba bean (FbWW), significantly increased the grain yield, grains spike^{-1} and spikes m^{-2} of wheat. Minimum tillage had no effect on wheat yield and yield components, but did reduce seedling density at emergence. The yield of bread wheat was more consistent over years than that of the other three crop species included in the trial. Conventional tillage increased wheat straw N% and straw N uptake relative to minimum tillage. The density of the weed species *Bromus pectinatus* and *Galinsoga parviflora* increased under minimum tillage; continuous wheat cropping and the wheat-barley rotation also increased the density of *B. pectinatus.* Neither tillage practice nor cropping sequence had an effect on take-all (*Gaeumannomyces graminis* f.sp. *tritici*) and eyespot (*Pseudocercosporella herpotrichoides*) incidence. The effect of interaction between tillage and cropping sequence was non-significant for all measured parameters. However, year by tillage and year by cropping sequence effects were significant for several parameters. Economic analysis indicated that the optimal production system consisted of the FbWW crop rotation under minimum tillage; conventional tillage was dominated by the minimum tillage system. Rotation of wheat with faba bean should be recommended for peasant farmers in Ethiopia as a means of increasing the grain yield of wheat and reducing the population of problematic grass weeds. In order to minimize soil losses due to erosion, the adoption of minimum tillage practices for small-scale wheat production in Ethiopia could be encouraged, since there was no difference among the tillage treatments in terms of the grain yield of wheat. However, farmers adopting minimum tillage for wheat production must be encouraged to practice crop rotation with faba bean in order to minimize the risk of an increase in the density of *B. pectinatus.*

INTRODUCTION

In specific zones of the highlands of Ethiopia (i.e., >2000 m a.s.l.), bread wheat occupies up to 45% of the total cropped area, and the majority of the wheat crop is cultivated by smallholders using the traditional ox traction system (Chilot *et al.*, 1992). Bread wheat yields remain low on peasant farms: the national mean wheat yield was estimated at about 1.4 t ha^{-1} during 1993-95 (CIMMYT, 1996). Such low yields are attributable to both agronomic and socio-economic constraints (Hailu *et al.*, 1988).

To alleviate the agronomic constraints confronting bread wheat production, it is important to examine integrated crop management practices. The combined effects of tillage practice and cropping sequence were previously evaluated at the Kulumsa Research Center in Ethiopia under both mechanized and ox-plow tillage systems (Asefa *et al.*, 1992). The principal objectives of soil tillage are to provide suitable seedbed conditions and adequate weed control (Triplett and van Doren, 1977; Lal, 1989). However, excessive mechanical soil manipulation leads to deterioration of soil structure, acceleration of soil erosion and runoff, and, consequently, a reduction of crop yield (Aina, 1979; Phillips *et al.*, 1980; Lal, 1989). Tillage systems can also affect various soil physical and chemical properties, including soil moisture, mechanical resistance, organic matter, nitrate and ammonium.

In recent years, however, a growing awareness of sustainability issues related to soil productivity has increased interest in soil and water conservation via reduced tillage crop production systems (Phillips *et al.*, 1980; Hargrove and Hardcastle, 1984; Lal, 1989). Reduced (minimum) tillage is a form of conservation tillage in which disturbance of the soil is reduced by minimizing the degree of tillage, including only those operations that are essential; appropriate herbicides are substituted for tillage, in order to create suitable conditions for seed germination, plant growth and weed control (Hamblin *et al.*, 1982; Triplett and van Doren, 1977).

Many studies have indicated that reduced tillage has an advantage in decreasing soil erosion and run-off and maintaining soil structure and long-term productivity (Hargrove and Hardcastle, 1984; Lal, 1989; Phillips *et al.*, 1980). The effects of conservation and conventional tillage have been evaluated in terms of minimizing production costs, safeguarding against soil loss, and boosting crop yields. Additional benefits of adopting conservation tillage are enhancement of water infiltration and increased soil organic matter (Triplett and van Doren, 1977; Aina, 1979; Lal, 1989; Asefa *et al.*, 1992).

The use of legumes in sequential cropping with wheat provides several benefits to sustainable and profitable crop production (Higgs *et al.*, 1990). In Ethiopia, a number of rotation and cropping sequence trials have indicated the importance of including dicots, particularly legumes, in the cropping system to improve yields and sustain production (Amanuel and Tanner, 1991). The benefits of such crop rotations include: N-fixation by the legume (Hargrove *et al.*, 1983); the interruption of weed (Heenan *et al.*, 1990), disease and insect cycles by dicotyledonous crops; crop diversification (Zentner and Campbell, 1988); improvement in soil tilth and a reduction in rainfall runoff and erosion (Higgs *et al.*, 1990).

Moreover, no studies have examined the long-term integrated effects of tillage and cropping sequence practices on the Ethiopian cropping environment. This study presents results generated during the 1992-1999 cropping seasons on a peasant farmer's field in the south-eastern highlands of Ethiopia.

MATERIALS AND METHODS

Site characteristics: The trial was initiated during 1992 at an on-farm site near Gonde in the vicinity of the Kulumsa research station (8°02'N, 39°10'E), located in the south-eastern highlands of Ethiopia at an altitude of 2200 m a.s.l. During the main crop growing season (i.e., June to November), long-term mean monthly minimum and maximum temperatures at Kulumsa were 10.6 and 22.1°C; mean precipitation during the main growing season was 504 mm. According to the agro-ecological zonation of Ethiopia, this site is located in the M2 agro-ecological zone (tepid to cool, moist highland). The site is located on a high clay content soil.

Trial design: The trial consisted of 8 treatments comprising the full factorial combination of: a) two levels of tillage (i.e., minimum tillage [MT] vs. conventional tillage) and four levels of cropping sequence (CS) (i.e., continuous bread wheat vs. a rotation of one year of faba bean, rapeseed, and barley followed by two years of wheat). The treatments were laid out in a split-plot arrangement in an RCBD with three replications. Tillage treatments were initiated in main plots of 10 x 20 m, and CS in sub-plots of 5 x 10 m in 1992. All treatment plots were maintained over the trial duration.

Crop management practices: Conventional tillage consisted of four ploughings prior to sowing (i.e., farmers' practice); for MT, one pass with the ox-plow was used to incorporate broadcast seed and fertilizer. For the MT treatment, chemical fallow was practiced during the "short rains" period each year: glyphosate was spray applied at 720 g a.i. ha^{-1} during the fallow period with a maximum of two applications per season (i.e., as required to prevent weeds from attaining a height of 20 cm).

Recommended cultural practices (i.e., for non-experimental crop management factors) were adopted for faba bean, rapeseed, barley, and bread wheat during the conduct of the trials. Over the period from 1992 to 1999, the trial was sown on dates ranging from June 29 to July 12. Bread wheat cultivars "Enkoy" (1992-93), and "Mitike" (1994) were sown at a seed rate of 150 kg ha^{-1} while "Kubsa" (1995-1999) was sown at a seed rate of 175 kg ha^{-1}. During 1992-94, bread wheat received a basal application of 41 kg N ha^{-1}, but from 1995-99, bread wheat received a basal application of 82 kg N ha^{-1}.

During 1992, 1995, and 1998, break crops were sown as follows: faba bean cultivar "CS20DK" at a seed rate of 200 kg ha^{-1}; rapeseed cultivar "Yellow Dodola" at a seed rate of 15 kg ha^{-1}; barley cultivar "Holker" (1992) at a seed rate of 80 kg ha^{-1} and cultivar "ARDU-12-60B" (1995, 1998) at a seed rate of 130 kg ha^{-1}. Basal N was applied at 18 kg ha^{-1} for faba bean, whereas, for rapeseed and barley, 41 kg N ha^{-1} was applied. All crops received a basal application of 46 kg P_2O_5 ha^{-1} each year. Due to the risk of damage by spray drift, hand weeding was used to control weeds during years in which all crops were sown (i.e., 1992, 1995, and 1998). During years in which all plots were sown to wheat (i.e., 1993, 1994, 1996, 1997, and 1999), weed control entailed a post-emergence spray application of a tank mix of fenoxaprop-p-ethyl + fluroxpyr + MCPA at 0.069 + 0.175 + 1.0 kg a.i. ha^{-1}, respectively.

Agronomic data: Data on various crop parameters were collected throughout the cropping season. Data on seedling density, maturity dates, plant height, and spikes m^{-2} were collected. A 9 m^2 net plot area was harvested by sickle to determine seed yield, thousand seed weight

and % seed moisture. Sample culms were harvested at ground level from each wheat plot to calculate biomass yield and harvest index.

Crop nutrient uptake: Grain and straw N contents were determined by micro-Kjeldahl analysis of grain and straw taken from oven-dried samples. Grain nitrogen uptake (GNU) and straw nitrogen uptake (SNU) values were calculated by multiplying grain and straw yields by the respective N contents. Total N uptake (TNU) was calculated as the sum of GNU and SNU.

Weed assessment: Data on broadleaf weed and grass weed seedling densities were collected each season from sub-plots using randomly placed quadrats prior to hand weeding; panicle and spike counts for individual grass weed species were also recorded at maturity of the wheat crop. Prior to analysis, weed density data were transformed using the square root of (actual counts + 0.5).

Disease assessment: The incidence of take-all and eyespot was estimated during 1994, 1996, 1997 and 1999 within each sub-plot. Each season, samples of main stems and tillers were collected for disease assessment immediately after crop harvest. Samples were collected by traversing a "W" pattern across each sub-plot. After washing and drying the stubble samples, a minimum of 80 crowns from each sub-plot were assessed for disease symptoms.

Eyespot severity was assessed using the 0-3 rating scale of Scott and Hollins (1974) in which 0 = crowns with no infection, 1 = slight infection, 2 = moderate infection, and 3 = severe infection. If eyespot lesions were not clearly visible, the internodes were split and checked for internal growth of the typical grayish, cottony mycelium to confirm the presence of the disease. The number of crowns in each severity class was recorded, and a weighted percent severity score for eyespot was calculated for each sub-plot using the following formula: (100 • Σ([number of crowns in each severity class] • [the severity class rating])) ÷ ([total number of crowns scored] • 3).

Take-all severity was assessed on the same sampled crowns using the 0-5 rating scale of Scott (1969) in which 0 = crowns with no infection, and 5 = severe infection. A weighted percent severity score for take-all was calculated for each sub-plot using the following formula: (100 • Σ([number of crowns in each severity class] • [the severity class rating])) ÷ ([total number of crowns scored] • 5).

Statistical analysis: Data from each experiment were combined over years. Analysis of variance was performed using the MSTATC statistical package and the grouping of means was determined using the LSD test at the 5% probability level.

Economic analysis: Grain and seed yield data from the trial (i.e., 8 treatment combinations) were subjected to partial budget analysis (CIMMYT, 1988). Grain and seed yields were adjusted downwards by 10%. Field prices for the four crops during the period between Dec. 1999 to Jan. 2000, adjusted for the cost of threshing, were 1.671, 1.591, 1.410 and 1.535 EB/kg for faba bean, rapeseed, barley and wheat, respectively. Seed was valued at the 1999-2000 farm-gate price of the output (i.e., farmers used "own" seed). The cost of weeding and harvesting the four crops was 272.00, 131.50, 218.00 and 259.50 EB/ha for faba bean, rapeseed, barley and wheat, respectively. Fertilizer costs were derived from the purchase price of fertilizer in the Gonde village during the 1999 planting season as follows: 137.03 EB/100 kg of urea and 228.04 EB/100 kg of DAP. For the conventional tillage practice, the

cost of tillage plus seed covering was estimated as 300 EB/ha (i.e., 5 passes by the ox-plow at 60 EB/pass/ha); for MT, the cost of tillage and fallow season weed control was estimated as 210 EB/ha (i.e., 720 g glyphosate/ha costing 140 EB/ha plus 10 EB/ha for application and 60 EB/ha for one pass with the ox-plow for seed covering).

Dominance analysis was used to select the superior treatments among the eight treatment combinations. The marginal rate of return (MRR) was calculated for each treatment (i.e., relative to the next lowest cost, non-dominated treatment).

RESULTS AND DISCUSSION

Yield and yield components: The results of the combined ANOVA for grain yield and yield components are presented in Table 1. Year and year by tillage effects comprised a high proportion of the total variability, reflecting pronounced environmental effects on wheat grain yield and yield components.

Tillage practice had no consistent effect on wheat grain yield and yield components (Tables 1 and 2); however, minimum tillage did reduce seedling density at emergence (Table 2). Minimum tillage has been stated to be a viable option for wheat production elsewhere in East Africa (Modestus, 1994); however, there was no apparent biological yield advantage due to MT in the current study. MT has been proposed as an alternative to conventional tillage where soil is prone to erosion (Aulakh and Gill, 1988; Stobbe, 1990), and to reduce evaporative losses and maintain soil moisture in drier environments (Griffith *et al.*, 1986). Other reports have indicated that MT can reduce wheat grain yields in specific environments (Kamwaga, 1990; Kirkegaard *et al.*, 1994).

The effect of interaction of tillage by year was significant for all parameters of grain yield and yield components, but was not significant for seedling density at emergence (Table 1). The interactions revealed differential effect of tillage practices over years for all yield components (Table 3). Grain yield was not affected by tillage in 3 out of 5 years, but was affected positively by MT in 1996 and adversely in 1999; HI was higher under MT in 3 out of 5 years; TKW was higher under MT in 3 out of 5 years but was lower in 1999 (Table 3). Wheat grain yield was markedly lower during the 1994 cropping season, due to adverse weather conditions, particularly strong winds coupled with reduced rainfall prior to the physiological maturity of the wheat crop; on the other hand, the highest mean wheat grain was obtained in 1996 because the weather conditions were conducive for the growth and development of the wheat crop.

Cropping sequence significantly affected grain yield, grains spike^{-1}, spikes m^{-2} and grains m^{-2} (Table 1). The three year crop rotation consisting of two consecutive crops of wheat following one crop of faba bean (FbWW) significantly increased these parameters, particularly relative to continuous wheat and the wheat-barley rotation (Table 2). Thus, dicot crops especially legumes, are recommended for inclusion in the cropping system. Several authors have emphasized the use of crop rotation to sustain wheat production (Higgs *et al.*, 1990; Baldock *et al.*, 1981).

The interaction effect of year by cropping sequence was highly significant for grain yield, grains m^{-2} and TKW (Table 1). In general, the interaction effects revealed that in some years the differences amongst treatments were NS. In the case of wheat grain yield (Table 4), precursor crop effects were NS during 1994 and 1997 – the second year following precursor

crop production (i.e., precursors were grown during 1992 and 1995). By contrast, precursor crop effects were significant for each wheat crop immediately following the precursors (i.e., 1993, 1996 and 1999). During 1993, FbWW outyielded RpWW; by contrast, in 1996 and 1999 these two treatments did not differ in yield. During 1999, continuous wheat was lower yielding than BaWW; however, in 1993 and 1996, these two treatments exhibited similar yield levels.

The number of grains m^{-2} differed amongst the cropping sequences each year except during 1997 (Table 4). Wheat in the faba bean rotation was superior to the other three cropping sequences in 1993 and 1994; however, in 1996 and 1999, wheat exhibited a similar number of grains m^{-2} following either faba bean or rapeseed.

The effects of CS on TKW were less consistent due to the typical plasticity of the response of TKW to the effects of treatments on other yield components. For example, FbWW in 1994 exhibited an increase in spikes per m^{-2} and grains per spike relative to the other precursor crop treatments (Table 2); however, due to the terminal drought stress experienced in 1994, the TKW of the FbWW treatment was markedly reduced (Table 4).

The three-way interaction effect (i.e., year by tillage by cropping sequence) was significant for grain yield, harvest index and grains m^{-2} (Table 1). Upon scrutiny of the three-way interaction means for grain yield (data not show), it appeared that conventional tillage combined with the faba bean rotation markedly increased grain yield in some years. Nonetheless, the main effect of cropping sequence was clearly apparent among the treatment means.

The data from the three years of precursor crop production revealed that the yield of continuous bread wheat was less variable over years than the yield of the other three crop species included in the trial (Table 5); C.V.s (i.e., calculated on plot yields without removing year and replication effects) ranged from 135% for wheat up to 345% for faba bean. Faba bean and rapeseed crops are known to be sensitive to environmental conditions (Tanner *et al.*, 1999), and this was reflected in the C.V. levels. The lower levels of variability associated with cereal production may also partially explain the predominance of cereals in the peasant farming systems of Ethiopia (i.e., yield stability enhances food security).

Wheat N uptake: The results of the combined analysis over two years for wheat N uptake (Table 6) revealed that conventional tillage markedly increased straw N% and straw N uptake. Christensen *et al.* (1994) found that wheat response to N fertilizer could vary with tillage system and soil moisture. Results reported by Rao and Dao (1992) suggested that cereals under MT may require additional fertilizer to attain similar production levels as under conventional tillage because of a lower extraction efficiency of available N. In general, the wheat crop N uptake was higher in 1996 and lower in 1997 (data not shown). Cropping sequence did not exhibit a significant effect on wheat N uptake.

Weed population dynamics: The results of the combined analysis over four years for weed densities are presented in Table 7. Tillage exerted a pronounced effect on weed seedling densities. *Polygonum nepalense* was markedly increased under conventional tillage, whereas, *Galinsoga parviflora* was increased by minimum tillage. Elsewhere, weed populations have been observed to build up rapidly under zero or MT (Arshad *et al.*, 1994; Blackshaw *et al.*, 1994), necessitating the use of increasingly sophisticated post-emergence weed management

practices; by contrast, some broadleaf weed species have been reported to germinate at a lower frequency under zero-tillage (Clements *et al.*, 1996; Giref *et al.*, 1992).

The density of *Guizotia scabra* was markedly increased in the RpWW CS, while *Polygonum nepalense* density increased in both the RpWW and FbWW sequences (Table 7). *Guizotia scabra* density apparently reduced over time, whereas *Polygonum nepalense* decreased during the middle of the trial period.

Although data were collected for different grass weed species, only one species, *Bromus pectinatus*, occurred at a high density over the trial period. Conventional tillage significantly reduced *Bromus* density (Table 7). Repeated tillage brings weed seeds to the surface and exposes them desiccation, and also buries seeds deep in the soil creating unsuitable conditions for germination and growth, thereby reducing the density of some weeds (Akobundu, 1987).

Bromus pectinatus density in wheat was significantly reduced by the use of dicot precursor crops, especially faba bean, cf. continuous wheat production. Higher infestations of the weed were observed in continuous wheat and the barley-based cropping sequence. Herbicidal weed control of other grass weeds by fenoxaprop-p-ethyl may have contributed to the opportunistic increase of this weed since the chemical does not control *Bromus* spp. Thus, rotation of wheat with faba bean is a promising means of reducing grass weed densities in wheat; the build-up of grass weed species in continuous wheat production systems has been reported elsewhere (Blackshaw *et al.*, 1994; Heenan *et al.*, 1990).

Incidence of root diseases: The results of the combined analysis over four years for root diseases are presented in Table 8. Neither tillage nor cropping sequence had an apparent effect on take-all and eyespot incidence. Year effects were more apparent, particularly in the case of eyespot: the level of eyespot reduced significantly in 1996 and increased during 1999. There was no significant difference over years in terms of take-all incidence.

Scott (1969) reported that cultivation significantly reduced the number of white heads caused by take-all in a wheat crop, and concluded that this was probably due to enhanced microbial activity in the well-aerated mixture of soil and stubble. Moore and Cook (1984) found that the best control of take-all in consecutive crops of wheat was achieved by thorough tillage; the same authors suggested that early loosening of ploughed soil hastened the decline of the take-all fungus relative to the more compacted soil under zero tillage. Herrman and Wiese (1985) reported that eyespot incidence was highest in MT plots, and lowest in zero tillage plots.

Cropping sequence and tillage practices may both influence the inoculum density of residue-borne pathogens (Sutton and Vyn, 1990). Production of wheat in sequence with non-host crops may suppress wheat pathogens by allowing more time for the organisms to decline in residues, by modifying the residue microclimate, or through other effects (Sutton and Vyn, 1990). De Boer *et al.* (1992) reported that rotation of wheat with leguminous crops reduced the levels of take-all and eyespot relative to continuously cropped wheat.

Economic analysis: The results of the partial budget analysis are presented in Table 9. The highest net benefits were associated with the faba bean and rapeseed cropping sequences. Conventional tillage treatments were dominated (i.e., cost more and produced lower net benefits) by minimum tillage. The lowest cost treatment was RpWW under minimum tillage.

The optimal treatment was FbWW under minimum tillage having an MRR of 2047% relative to RpWW under minimum tillage. All other treatments were dominated by the optimal treatment. The indices of variability (i.e., a measure of the variability of NB) ranged between 40.8 and 63.2% for the eight treatments; the optimal treatment exhibited an acceptable I.V. of 47.3%.

CONCLUSIONS

Crop management practices differed in their impact on the various parameters of the wheat production systems. Tillage had no consistent effect on wheat yield and yield components, but MT reduced seedling density at emergence. Conventional tillage increased wheat straw N% and N uptake as compared to minimum tillage. *Bromus pectinatus* and *Galinsoga parviflora* densities increased under minimum tillage; continuous wheat cropping and the wheat-barley based rotation also increased the density of *B. pectinatus*. Neither tillage nor cropping sequence affected the incidence of take-all and eyespot diseases of wheat. The results of the economic analysis revealed that the optimal production system consisted of a FbWW cropping sequence under minimum tillage. Therefore, rotation of wheat with faba bean should be recommended for small-holders in Ethiopia as a means of increasing the grain yield of wheat, reducing the population of problematic grass weeds, and increasing the income of farmers. In order to reduce soil losses due to erosion, adoption of minimum tillage for small-scale wheat production in Ethiopia could be encouraged, since there was no difference among the tillage treatments in terms of the grain yield of wheat. However, farmers adopting minimum tillage for wheat production must be encouraged to practice crop rotation with faba bean in order to reduce the risk of an increase in the density of *B. pectinatus*.

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Questions and Answers:

John Tolmay: Were any soil moisture measurements taken on different tillage treatments? If any, were any differences found in soil moisture?

Answer: There were no significant differences between tillage treatments for the data recorded in 1994, 1996 and 1997.

Bedada Girma: Your results showed that tillage or cropping sequence had no effect on take-all and eyespot diseases. If so, what possible recommendations would you suggest for the control of wheat root diseases?

Answer: Seed treatment with chemicals and the use of a resistant variety for both diseases.

H. Mansoor: The CVs on your ANOVA were quite high (135-300%). Do you have any explanation on the CVs? Would you be confident to recommend anything with these high CVs?

Answer: The year and rep. effects were not pulled out. That is why the CV was very high.

Table 1. Crop management effects on wheat yield and yield components in the Gonde on-farm trial: ANOVA results across five years (1993-94, 1996-97, 1999).

	GY	SD	HI	GPM	SPM	GPS	TKW
Year (Y)	***	***	***	***	***	***	***
Tillage (T)	NS	**	NS	NS	NS	NS	NS
Y x T	**	NS	***	*	*	*	***
Cropping sequence (C)	*	NS	NS	*	**	*	NS
Y x C	***	NS	NS	***	NS	†	**
T x C	NS	NS	NS	NS	NS	NS	NS
Y x T x C	*	NS	*	*	NS	NS	NS
Mean	3179	276	38.8	10120	362	26.8	31.4
C.V. (%)	12.3	18.8	8.88	11.1	19.1	18.7	7.14

†, *, **, *** Significant at the 10, 5, 1 and 0.1% levels, respectively.
When significant at the 5% level, the mean square for interaction with years (e.g., a random factor) was used as the denominator for the F-test of the corresponding fixed factor (i.e., T, C, and/or T x C).
GY = Grain yield (kg/ha); SD = Seedling density/m^2; HI = Harvest index (%); GPM = Grains/m^2; SPM = Spikes/m^2; GPS = Grains/spike; TKW = Thousand kernel weight (g).

Table 2. Crop management effects on wheat yield and yield components in the Gonde on-farm trial: treatment means across five years (1993-94, 1996-97, 1999).

	GY	SD	HI	GPM	SPM	GPS	TKW
Tillage							
Conventional	3132	289A	37.7	10280	376	28.4	30.4
Minimum	3226	262B	39.9	9961	348	29.3	32.3
Cropping sequence							
Faba bean-W-W	3691A	289	39.7	11583A	384A	31.6A	31.8
Rapeseed-W-W	3365AB	286	38.4	10528B	384A	27.8B	31.9
Barley-W-W	2927BC	262	38.1	9498C	345B	28.5B	30.8
Continuous wheat	2732C	266	39.1	8873D	334B	27.5B	30.9
LSD(5%)	548.8	NS	NS	500	35.7	2.78	NS

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

GY = Grain yield (kg/ha); SD = Seedling density/m^2; HI = Harvest index (%); GPM = Grains/m^2; SPM = Spikes/m^2; GPS = Grains/spike; TKW = Thousand kernel weight (g).

Table 3. Effects of interaction of tillage by year on grain yield and yield components of wheat in the Gonde on-farm trial.

	Grain yield (kg/ha)		Harvest index (%)		Grains/m^2		Spikes/m^2		Grains/spike		TKW (g)	
Year	**Con**	**Min**	**Con**	**Min**	**Con**	**Min**	**Con**	**Min**	**Con**	**Min**	**Con**	**Min**
1993	2443	2690	34.7	33.2	9279	9712	431	445	22.0	22.0	26.3B	27.6A
1994	1591	1762	27.9B	29.9A	5544	6103	354	314	16.0	19.5	28.7	29.2
1996	4343B	4906A	37.8B	43.7A	14375	14922	430	401	34.0	37.6	29.9B	32.8A
1997	3629	3830	43.8B	48.2A	12325A	10891B	288	302	43.1A	36.3B	30.4B	36.3A
1999	3652A	2942B	44.2	44.9	9875A	8177B	375A	278B	26.6	31.0	36.9A	35.5B
LSD(5%)	393		1.76		1193		53		4.4		1.23	

Values followed by the same or no letters within a year for each parameter are not significantly different at the 5% level of the LSD test.
Con = Conventional tillage; Min = Minimum tillage; TKW = Thousand kernel weight.

Table 4. Effects of interaction of cropping sequence by year on grain yield and yield components of wheat in the Gonde on-farm trial.

	Grain yield (kg/ha)					Grains/m^2					Thousand kernel weight (g)				
CS	**1993**	**1994**	**1996**	**1997**	**1999**	**1993**	**1994**	**1996**	**1997**	**1999**	**1993**	**1994**	**1996**	**1997**	**1999**
Fb-W-W	3293A	1922	5176A	3861	4206A	12431A	6920A	15584A	12101	10877A	26.4	27.7B	33.2A	33.1	38.8A
Rp-W-W	2713B	1602	4944A	3730	3837A	9839B	5507B	15615A	11546	10133AB	27.4	29.6AB	31.6AB	33.4	37.5AB
Ba-W-W	1935C	1640	4311B	3627	3122B	7054C	5316B	14046B	11712	9364B	27.3	30.8A	30.4B	32.3	33.3C
Continuous W	2326BC	1543	4067B	3700	2023C	8660B	5551B	13348B	11073	5731C	26.8	27.6B	30.2B	34.5	35.2BC
LSD(5%)	450					1295					2.59				

Values followed by the same or no letters within a column for each parameter are not significantly different at the 5% level of the LSD test.
CS = Cropping sequence; Fb = Faba bean; Rp = Rapeseed; Ba = Barley; W = Wheat.

Table 5. Precursor crop yields (kg/ha) by tillage treatment in the Gonde on-farm trial (mean of 1992, 1995, 1998).

	Tillage		C.V.(%) (n=18)
Precursor crop	**Conventional**	**Minimum**	
Faba bean	2573	2470	345
Rapeseed	2267	1945	323
Barley	2310	2030	193
Wheat	2162	1775	135

Table 6. Crop management effects on wheat N uptake in the Gonde on-farm trial: treatment means (1996, 1997).

	GN%	SN%	GNU	SNU	TNU
Tillage					
Conventional	1.81	0.51A	63.4	28.0A	91.7
Minimum	1.75	0.43B	67.6	21.2B	88.8
Cropping sequence					
Faba bean-W-W	1.86	0.47	74.3	24.7	98.9
Rapeseed-W-W	1.80	0.46	68.1	26.4	94.9
Barley-W-W	1.74	0.49	61.0	25.5	86.5
Continuous wheat	1.72	0.46	58.7	21.8	80.5

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

SN% = Straw N (%); GN% = Grain N (%); GNU = Grain N uptake (kg/ha); SNU = Straw N uptake (kg/ha); TNU = Total N uptake (kg/ha).

Table 7. Crop management effects on weed population dynamics in the Gonde on-farm trial: treatment means[a] (1993, 1994, 1996, 1999).

	Bromus pectinatus	*Guizotia scabra*	*Polygonum nepalense*	*Galinsoga parviflora*
Tillage				
Conventional	4.86B	3.21	10.3A	2.33B
Minimum	6.43A	3.66	9.2B	3.35A
Cropping sequence				
Faba bean-W-W	3.72C	3.12B	10.7A	2.65
Rapeseed-W-W	5.12BC	4.27A	10.2A	2.83
Barley-W-W	6.34AB	3.02B	8.1B	2.83
Continuous wheat	7.41A	3.33B	9.9AB	3.06
LSD (5%)	2.10	0.76	1.88	
Year				
1993	10.1A	4.61A	14.4A	3.17
1994	4.6B	4.28A	8.5C	3.10
1996	3.5B	2.19B	5.2D	3.09
1999	4.4B	2.66B	10.7B	2.01
LSD(5%)	3.11	0.97	1.78	NS

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.

[a]Means based on transformed data [i.e., based on SQRT(weed count/m^2 + 0.5)].

Table 8. Crop management effects on the incidence take-all and eyespot diseases on wheat in the Gonde on-farm trial: treatment means[a] (1994, 1996, 1997, 1999).

	Take-all	Eyespot
Tillage		
Conventional	1.99	4.21
Minimum	2.11	3.40
Cropping sequence		
Faba bean	1.80	3.82
Rapeseed	1.66	4.15
Barley	2.25	4.21
Wheat	1.90	4.12
Year		
1994	1.50	4.30B
1996	1.57	1.87C
1997	3.10	4.04B
1999	2.04	6.10A
LSD(5%)	NS	0.74

Values for an individual factor level within a column followed by the same or no letters are not significantly different at the 5% level of the LSD test.
[a]Means based on transformed data [i.e., based on SQRT(weighted percent severity score + 0.5)].

Table 9. Results of the partial budget analysis of eight years of seed yield in the Gonde on-farm trial (1992-1999).

Tillage	CS	TCV (EB/ha)	NB (EB/ha)	MRR (%)	I.V. (%)
Minimum	Rapeseed	775	3260	--	57.9
Minimum	Faba bean	802	3813	2047	47.3
Minimum	Barley	808	2739	D	58.9
Minimum	Wheat	854	2415	D	63.2
Conventional	Rapeseed	854	3184	D	61.7
Conventional	Faba bean	881	3723	D	56.4
Conventional	Barley	886	2687	D	49.4
Conventional	Wheat	932	2555	D	40.8

CS = Cropping sequence; TCV = Total costs that vary; NB = Net benefit;
MRR = Marginal rate of return; IV= Index of variability of NB.

SURVEY OF WEED COMMUNITY STRUCTURE IN BREAD WHEAT IN THREE DISTRICTS OF ARSI ZONE IN SOUTH-EASTERN ETHIOPIA

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ABSTRACT

Survey and monitoring of weed community structure was conducted in 1999 in three major wheat growing districts of Arsi Zone. The survey was conducted twice during the cropping season. Weed species were counted and farmers were interviewed regarding different aspects of weeds and weed management practices. Overall, 45 weed species were identified in the surveyed area. The frequency of occurrence of individual weed species in the surveyed area ranged from 1.9 to 98.1%. The most frequently occurring broadleaf weed species included *Polygonum nepalense*, *Guizotia scabra*, *Galium spurium*, *Anagallis arvensis*, *Galinsoga parviflora* and *Chenopodium* spp. Grass weed species occurring with high frequency included *Bromus pectinatus*, *Phalaris minor* and *Lolium temulentum*. The broadleaf weed species with highest mean field densities were *Polygonum nepalense*, *Galium spurium*, *Guizotia scabra*, *Galinsoga parviflora*, *Cotula abyssinica* and *Anagallis arvensis*. The grass weeds *Phalaris minor*, *Bromus pectinatus*, *Lolium temulentum* and *Setaria pumila* exhibited the highest mean field densities. Farmers ranked *Galium spurium*, *Guizotia scabra*, *Rumex bequartii* and *Polygonum nepalense* as the most frequent problematic broadleaf species, while *Snowdenia polystachya*, *Bromus pectinatus*, *Avena fatua* and *Lolium temulentum* were identified as the most troublesome grass weeds. Of the farmers interviewed, 57.7% selected *Bromus pectinatus, Argemone mexicana* and *Polygonum convolvulus* as new problem weeds. Generally, the weed count data and farmers' identification of problem weed species were in agreement.

INTRODUCTION

Successful weed management requires understanding arable land weed communities (Swanton *et al.*, 1993). Knowledge of weed community structure is an important component of modern weed management research (Zonderwijk, 1982). The presence of each weed population in a field represents the results of ecological reactions to management practices of the current and previous years, edaphic factors of the site and the regional climate as weed distribution is regional in nature (Frick and Thomas, 1992). Weed populations in a given year also reflect local weather conditions and the resulting effects on recruitment, survival and competitive ability (Hidalgo *et al.*, 1990). In addition, weed management practices including chemical, cultural and mechanical methods used may also exert a selective influence on the weed populations (Zanin *et al.*, 1992; Sagvedra *et al.*, 1990) providing the impetus for survey of weed population. Community studies, therefore, may help to detect the significant interaction among weed communities, environment and management practices (Naavas,

1991). Moreover, this kind of ecological study helps to understand the impact of changing management (Zanin *et al.*, 1992; Thomas, 1985).

Weeds occurring in wheat growing areas of Arsi represent a major production loss. But since all weed species do not equally contribute to this loss, it is important to know the relative importance of weed species. In the past the weed composition of Arsi was assessed (ARDU, 1982). Recently survey results were documented from wheat growing areas of West Shewa and Bale (Taye and Yohannes, 1999; Kedir *et al.*, 1999). In Arsi, Giref and Workiye (1997) reported survey results of large-scale state owned farms around Asasa plain. The survey did not consider the small-scale farmers' fields and also were confined to specific areas of the wheat belt of Arsi. Moreover, the survey data was not collected in such a way that it could be quantitatively interpreted to aid weed management decisions. No survey work was done to characterize the weed community of the current survey area and baseline information is lacking to at least reproduce from survey results indicated above. Additionally, cereal based cropping is bringing to light new problems. Part of this involves the weed flora and management decisions required by growers to avert this problem.

The objective of the survey was therefore to document quantitative and qualitative aspects of the weed community occurring in wheat in wheat growing areas of Digelu-Tijo, Munesa and Tiyo districts, so as to help devise crops and implement proper weed management strategies.

MATERIALS AND METHODS

Description of the Area

The survey was conducted in wheat growing areas of Digelua-Tijo district and parts of Munesa and Tiyo districts. The altitude of the surveyed area ranged from 2240 to 2740 m a.s.l. Soil types of the surveyed area varied from heavy black soil to red soils with textural groups ranging from clay to sandy loam. In this survey the areas covered lay in two sub-AEZs namely M_{2-7} and H_{2-7} (tepid to cool moist humid highlands). The survey area was classified into three soil and altitude ranges to determine uniformity indices of weed species.

Sampling Procedure

A total of 62 farmers' fields were surveyed. The number of fields to be sampled were determined using the method outlined in Taye and Yohannes (1998). Every 5 km, 3-4 fields were surveyed following different routes. A field was sampled for counting weeds using an inverted W pattern described by Thomas (1985) with 4 quadrats, each 0.25 m^2. The number of plants was counted in each quadrat. In all cases, individual plants were counted ignoring tillers or other vegetative shoots in the case of annuals or perennials, respectively. In some instances it was difficult to identify species by name and grouping was made by genera. The survey was conducted twice (before weeding and at anthesis of wheat) during the main rainy season in the same fields. The time frame was chosen so that the weed counts reflected the impact of the agronomic management decision made by farmers to produce wheat. Farmers were interviewed on different aspects of their cropping systems and weed management practices and problems related to weeds.

Data Analyses and Summary

The data from different fields were combined and summarized using frequency, density (both mean field density and mean occurrence field density), dominance and similarity index (Thomas, 1985).

Frequency (F): is defined as the number of fields in which a weed occurred, expressed as a percentage of the total number of surveyed fields, and is an estimate of geographic extent of the weed in the study area.

$$F_k = 100*(\sum y_i/n)$$

where, F_k is frequency of species k, y_i is presence 1 or absence 0 of species k in field i, and n is number of fields surveyed.

Density: is defined as the mean number of plants per square meter. Two measures of densities were considered. **Mean field density** (MFD) is obtained by summing all the densities of a weed and dividing by the number of fields in which the weed occurred. **Mean occurrence field density** (MOFD) is obtained by summing all the densities of a weed and dividing by the number of fields in which a weed species occurred.

$$MFD_k = (\sum Di/n)$$
$$MOFD_k = (\sum Di/(n-a))$$

where, Di is density (expressed as no. m^{-2}) value of species j in field I, n is the same as above, and a is the number of fields where species j is absent.

To detect the existence of possible groups in the weed flora, a scatter plot of frequency versus mean field density was prepared.

Dominance (D): This is a measure of mean field density of species k (MFD_k) expressed as percentage of the total mean field density of all weed species (MFD_t).

$$D = 100*(MFD_k/ \sum MFD_t)$$

Similarity index (SI): The survey area was divided into three groups based on soil type and altitude range. The first group included light soil area with altitude ranging from 2240 to 2470 m. The second group was a black soil area, with altitude ranging from 2260 to 2520. The third group was red soil area with altitude ranging from 2510 to 2710 m. Similarity indices (SI) of weed species occurring in the three groups were calculated using the following formula. The formula compares two groups at a time and determines the degree of similarity of weed species in the specified groups in the current context.

$$SI = 100*(g_{ij}/(g_{ij} + g_i + g_j))$$

Where, g_{ij} is no. of species found in groups i and j
g_i is no. of species found only in group i and not in j
g_j is no. species found only in group j and not in i

RESULTS AND DISCUSSION

Quantitative Analysis of Weed Flora of the Surveyed Area

Overall 45 weed species were identified in the surveyed area which belonged to a total of 23 families of plants. Only seven families contained two or more weed species in number. Of these, Poaceae contributed 10 species, Compositae contributed seven species, Polygonaceae four and two species for each of Boraginaceae, Caryophylaceae, Labiatae and Leguminosae families. The prevalent weed species enlisted here were annuals reproducing by seed with high plasticity and seed setting capacity. Most of weed species important in wheat belonged to these families although there were single species families that can not be ignored (e.g., *Galium spurium* in family Rubiaceae).

The frequency of weed species in the surveyed area ranged from 1.9 to 98.1%. 31 weed species infested 5% or more of the fields (Table 1) representing 16 families. The most often occurring broadleaf weed species (F>38%) included *Polygonum nepalense*, *Guizotia scabra*, *Galium spurium*, *Anagallis arvensis*, *Galinsoga parviflora*, *Chenopodium* spp., *Cotula abyssinica*, and *Rumex bequartii*. Similarly, grass weed species with high level of frequency (F>73%) were *Bromus pectinatus*, *Phalaris minor* and *Lolium temulentum*.

Mean field densities ranged from 0.04 to 203.5 plants m^{-2} (Table1). Broadleaf weed species with high (>6 plants m^{-2}) mean field densities were *Polygonum nepalense*, *Galium spurium*, *Guizotia scabra*, *Galinsoga parviflora*, *Cotula abyssinica*, *Anagallis arvensis* and *Oxalis corniculata* in that order. Of the grasses, *Phalaris minor*, *Bromus pectinatus*, *Lolium temulentum* and *Setaria pumila* exhibited higher (5 plants m^{-2}) mean field density.

The mean occurrence field density ranged from 2 to 207 plants m^{-2}. Identifying weed community structure using this method offers wheat growers to know the situation of a weed species in the fields where the weed occurs. Although it is a liberal measure, it is helpful in designing control measures at farm level.

To detect the existence of possible groups in the weed flora, a scatter plot of frequency versus mean field density was prepared (Figure 1). Accordingly, the first group, with the highest frequency (98.1%) and MFD (203.5 plants m^{-2}) contained only *Polygonum nepalense*. The second group with still relatively high frequency (≥75%) and intermediate MFD (55.2 to 96.9 plants m^{-2}) included only two weed species belonging to Poaceae: *Phalaris minor* and *Bromus pectinatus*. The third group contained two species (*Guizotia scabra* and *Galium spurium*) with high frequency (>92%) and MFD between 19.9 and 45.4 plants m^{-2}. The fourth group contained two species with frequency between 61.3 and 73.1% and MFD between 6.1 and 8.2 plants m^{-2}. The species included here were *Anagallis arvensis* and *Lolium temulentum* belonging to families Caryophyllaciae and Poaceae, respectively. The fifth group included six weed species with frequency ranging from 36.5 to 44.2% and MFD between 2.6 and 9.4 plants m^{-2}. The species clumped together here were *Misopates orantium*, *Oxalis corniculata*, *Galinsoga parviflora*, *Rumex bequartii, Cotula abyssinica*, *Cearastium octandrum* belonging to five families. The sixth group included 18 weed species with frequency between 5.8 and 28.9% and MFD 0.38 to 7.4 plants m^{-2}. The 14 weed species recorded in the survey but not included in Figure 1 were considered infrequent, occurring in <5% of the fields at a mean density <0.4 plants m^{-2}. Identifying the possible association among different weed species will help practically to design sound weed control strategy for group of weed species based not only on their occurrence but also their density (Thomas and Ivany, 1990). However,

densities do not take into consideration the size of the weeds (McCully *et al.*, 1991). *Polygonum nepalense* is a relatively short, small plant which grows below wheat canopy except when well established ahead of the wheat crop. As recorded in the survey, this weed had the highest frequency and MFD but poses no significant threat compared to weed species like *Galium spurium*, *Guizotia scabra*, *Bromus pectinatus* and *Avena fatua* which are very problematic in wheat.

Dominance analysis. The dominance analysis of weed species indicates which weed species dominate across the surveyed area. Dominance for the surveyed area ranged from 39.4% (for *Polygonum nepalense*) to 0.007% (for *Myosotis orantium* and *Spilanthes mauritiana*). Only five species exhibited dominance levels greater than 3, while 7 species had dominance levels between 1.1 and 1.7%. The other species had dominance levels < 1%.

Generally, from the frequency, density and dominance analysis, the flora was dominated by a few species from which one can infer that a few weed species are important to wheat growers in the surveyed area. This gives farmers the opportunity to design strategic weed management. Therefore, given the appropriate attention and proper planning, farmers can easily manage problem weed species in the surveyed area.

Similarity Index. The three groups formed from different soil types and altitude ranges showed different similarity index ranges (Figure 2). The light versus black soil weed flora exhibited 77.1% similarity. However, the comparison of weed species composition between light versus red and black versus red soils (46.5 and 51.2%, respectively) fell below the threshold similarity index (60%) to claim that two groups are similar. From management perspective, weed management decision can be made for the light soils and black soil areas of the surveyed districts. However, the red soil weed flora since the Similarity index value is lower (compared with both light and black soils), it is important to must be dealt with separately.

Qualitative Assessment of the Weed Flora and Farmers' Perception of Weed Problem and Management Strategies

Cropping Practice. Farmers in the surveyed area practice cereal rotation or continuous cropping of wheat (51%), cereal based fallowing (30%) and rotation with dicot crops (19%). Further analysis of farmers' cropping practices and weed counts of surveyed area indicated that there was an apparent density difference in the different cropping patterns (Figure 3). Accordingly, total grass and broadleaf weed counts per field showed a consistent trend in which density was higher when farmers practice cereal or continuous cropping and lower when rotation was exercised.

Weed control practices. Farmers' weeding practices involve hand weeding (25%), herbicidal weed control (46.2%) or both (28.8%). More than 90% of farmers exercising hand weeding perform one time weeding which is usually light. Labor demand for hand weeding is directly related to the weed infestation level which is in turn influenced by the variety, seed source, cropping systems and weather conditions. The daily wage rate is estimated to be 5 EB per day. To hand weed a hectare of field, on average, 40 workdays suffice.

Most farmers in the surveyed area apply 2,4-D except 2% of them who are using grass killer herbicides. Due to this, farmers exercise supplementary hand weeding to remove grass weeds and prevent crop damage. Although farmers apply a great deal of 2,4-D on their wheat field,

the rate they use tremendously varies from the recommended rate. Most farmers (71.4%) apply less than the recommended rate of herbicide. Indeed, 48.6% of the farmers in the surveyed area apply half or less than half the recommended rate. This has an impact on the whole weed management strategy in that, first, by reducing the herbicide rate, desirable efficacy will not be attained. Second, from the economics perspective, it is a waste of money. Thirdly, there can be a danger of introducing herbicide resistant biotypes by reducing the rate although this is not a common phenomenon with auxinic type of herbicides. The reasons farmers use below recommended rate are several. To mention a few, the price of herbicide plays greater role. The average price of 2,4-D is 50 EB per liter. This amount is higher than the cash investment capacity of farmers. Another factor is cost associated with spraying and spray equipment. Usually farmers reduce the number of tanks so as to minimize the amount of money they pay. In such cases, the applicators rush through the field without uniform coverage of the field. Additionally, when farmers buy herbicide from local merchants, quite frequently they are deceived since the merchants add odd materials into the actual content of the herbicide which actually reduce the rate without the knowledge of the farmer. Besides, farmers have no idea of calibration and they apply spray mix in unorganized way in the field.

Associated with herbicides is the use of protective measures. Seventy six percent of farmers applying herbicide used no protectives and those who used protectives were using a piece of cloth to cover their nose and mouth. More than 90% of the farmers are aware of the danger associated with herbicides on human health.

Alternative weed management. Farmers either use hand weeding or herbicides so as to eliminate weeds from their field. Of the farmers interviewed on alternative measures to control weeds, 55% thought of no alternative weed control strategies other than hand weeding and herbicides. Even this group of farmers are not in a position to think of operations like tillage as practices for managing weeds. Those farmers who exercise alternative weed management methods suggested tillage, fallowing, rotation and higher seed rate as options to reduce weed population. Some farmers are adding diesel oil in the 2,4-D spray mix with the assumption that it will kill *Galium spurium*, a weed species weakly controlled on farmers field by 2,4-D.

Yield loss due to weeds. Yield loss due to weeds, compared with other pests (diseases and insects) was ranked 3rd. The major reasons for this were first, weed problem is understood as a predictable problem in which farmers plan weed control ahead and they are sure that weed control is inevitable. On the other hand, disease and insect problems are unpredictable and no preparedness against them by farmers can be made ahead so as to prevent loss of yield. Second, weed control options are readily available than other pests which give comfort to farmers when viewing weeds as problem pests. Despite this, all farmers agreed that of all pests, the cost incurred to control weeds exceeds that of other pests summed together. Also from the interview, if weeds are left uncontrolled, on average 50% yield reduction is apparent, although total yield loss due to weeds is uncommon.

Farmers were asked which weed species are most difficult to incur yield loss. They ranked *Galium spurium*, *Guizotia scabra*, *Rumex bequartii* and *Polygonum nepalense* as the most troublesome broadleaf weeds while *Snowdenia polystachya*, *Bromus pectinatus*, *Avena fatua* and *Lolium temulentum* as the most troublesome grass weed species. Farmers' assessment of the problem weeds somehow agrees with the quantitative analysis obtained from the survey.

Another aspect of loss reflected due to weeds involves that of market price of produce. Farmers carrying wheat grain infested with weed seed always get on average 30% less price than those farmers carrying clean seed. This has direct relation with the type of weed management that farmers exercise.

New weed problems. Farmers were asked if they came across new weed species or if weeds that had not been important had recently become so. Accordingly, 42.3% of the farmers interviewed responded 'no' while 57.7% responded 'yes'. Of the 57.7% responded 'yes' 28.9% identified *Bromus pectinatus*, 5.9% *Argemone mexicana* and 2% *Polygonum convolvulus*. The rest identified weed species like *Phalaris minor*, *Galium spurium* and *Guizotia scabra* as new weed problems in their area.

CONCLUSIONS AND RECOMMENDATIONS

In the current survey, the following conclusions and recommendations can be drawn for researchers, extension workers and farmers.

- The survey has documented the species and their relative importance in wheat.
- The data from current survey is the first of its kind in the surveyed area; therefore, the data can be used in the future to determine the impact of crop management and other factors on the weed species composition and community structure.
- The first eight major weeds with high mean density and dominance are *Polygonum nepalense*, *Phalaris minor*, *Bromus pectinatus*, *Galium spurium*, *Guizotia scabra*, *Galinsoga parviflora*, *Cotula abyssinica*, *Anagallis arvensis*.
- Since the major weed species are limited in number, designing an effective weed management strategy for the surveyed area should be relatively simple.
- Farmers and development workers should give due attention to new problem weeds before they become difficult for management.

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Table 1. Weed species characteristics and quantitative analysis of Digelu and Tijo, parts of Tiyo and Munesa districts, 1999.

Botanical name	Family	characteristics			F	MFD	MOFD	Domin
Amaranthus spp.	*Amaranthaceae*	a	d	s	7.69	0.81	10.50	0.16
Anagallis arvensis	*Primulaceae*	a	d	s	61.54	8.23	13.38	1.59
Alchemilla abyssinica	*Rosaceae*	a	d	s	3.85	0.27	7.00	0.05
Avena fatua	*Poaceae*	a	m	s	3.85	0.27	7.00	0.05
Bromus pectinatus	*Poaceae*	a	m	s	76.92	55.19	71.75	10.68
Cerastium octandrum	*Caryophylaceae*	a	d	s	36.54	4.00	10.95	0.77
Chenopodium spp.	*Chenopodaceae*	a	d	s	38.46	2.96	7.70	0.57
Commelina banghalensis	*Commelinaceae*	a/p	d	s/v	11.54	0.85	7.33	0.16
Corrigiola capensis	*Caryophylaceae*	a	d	s	28.85	3.31	11.47	0.64
Cotula abyssinica	*Compositae*	a	d	s	38.46	8.92	23.20	1.73
Cynodon dactylon	*Poaceae*	p	m	s/v	15.38	0.96	6.25	0.19
Cynoglssum lanceolatum	*Boraginaceae*	a	d	s	1.92	0.23	12.00	0.04
Cyperus spp.	*Cyperaceae*	p	m	s/v	19.23	7.38	38.40	1.43
Daucus carrota	*Umbelliferae*	a/b	d	s	28.85	3.04	10.53	0.59
Digitaria abyssinica	*Poaceae*	p	m	s/v	17.31	3.12	18.00	0.60
Eragrostis aspera	*Poaceae*	a	m	s	9.62	0.50	5.20	0.10
Erucastrum arabicum	*Cruciferae*	a	d	s	25.00	2.15	8.62	0.42
Euphorbia spp.	*Euphorbiaceae*	a/p	d	s	1.92	0.08	4.00	0.01
Galinsoga parviflora	*Compositae*	a	d	s	40.38	9.42	23.33	1.82
Galium spurium	*Rubiaceae*	a	d	s	92.31	45.38	49.17	8.78
Ganaphalium declinatum	*Compositae*	a	d		11.54	4.19	36.33	0.81
Guizotia scabra	*Compositae*	a	d	s	94.23	19.85	21.06	3.84
Haplocarpha shimperi	*Compositae*	a/p	d	s	5.77	0.92	16.00	0.18
Lamium spp.	*Labiatae*	a	d	s	3.85	0.08	2.00	0.01
Lolium temulentum	*Poaceae*	a	m	s	73.08	6.12	8.37	1.18
Misopates orantium	*Scrophulariaceae*	a	d	s	44.23	4.81	10.87	0.93
Myosotis arvensis	*Boraginaceae*	a	d	s	1.92	0.04	2.00	0.01
Ocimum spp.	*Labiatae*	a	d	s	3.85	0.38	10.00	0.07
Oxalis corniculata	*Oxalidaceae*	a/p	d	s/v	42.31	6.15	14.55	1.19
Pennisetum spp.	*Poaceae*	p	m	s/v	3.85	0.58	15.00	0.11
Phalaris minor	*Poaceae*	a	m	s	75.00	96.88	129.18	18.75
Plantago lanceolata	*Plantignaceae*	a/b	m	s	15.38	1.12	7.25	0.22
Polygonum convolvulus	*Polygonaceae*	a	d	s	3.85	0.35	9.00	0.07
Polygonum nepalense	*Polygonaceae*	a	d	s	98.08	203.54	207.53	39.38
Portulaca oleracea	*Portulacaceae*	a	d	s/v	1.92	0.12	6.00	0.02
Ranunculus spp.	*Ranunculaceae*	p	d	s	3.85	0.15	4.00	0.03
Rumex abyssinicus	*Polygonaceae*	a	d	s/v	5.77	0.38	6.67	0.07
Rumex bequartii	*Polygonaceae*	a	d	s/v	38.46	2.58	6.70	0.50
Setaria pumila	*Poaceae*	a	m	s	17.31	5.77	33.33	1.12
Snowdenia polystachya	*Poaceae*	a	m	s	15.38	3.23	21.00	0.63
Solanum nigrum	*Solanaceae*	a	d	s	3.85	0.42	11.00	0.08
Sonchus oleraceus	*Compositae*	a	d	s	25.00	1.15	4.62	0.22
Spilanthus mauritiana	*Compositae*	a	d	s	1.92	0.04	2.00	0.01
Trifolium spp.	*Leguminosae*	a	d	s	17.31	0.69	4.00	0.13
Vicia dicarpa	*Leguminosae*	a	d	s	3.85	0.54	14	0.10

a, b, p, m, d, represents annual, binnial, perennial, monocotyeldon, dicotyeldon while s and v represent reproduction by seed and vegetative means.

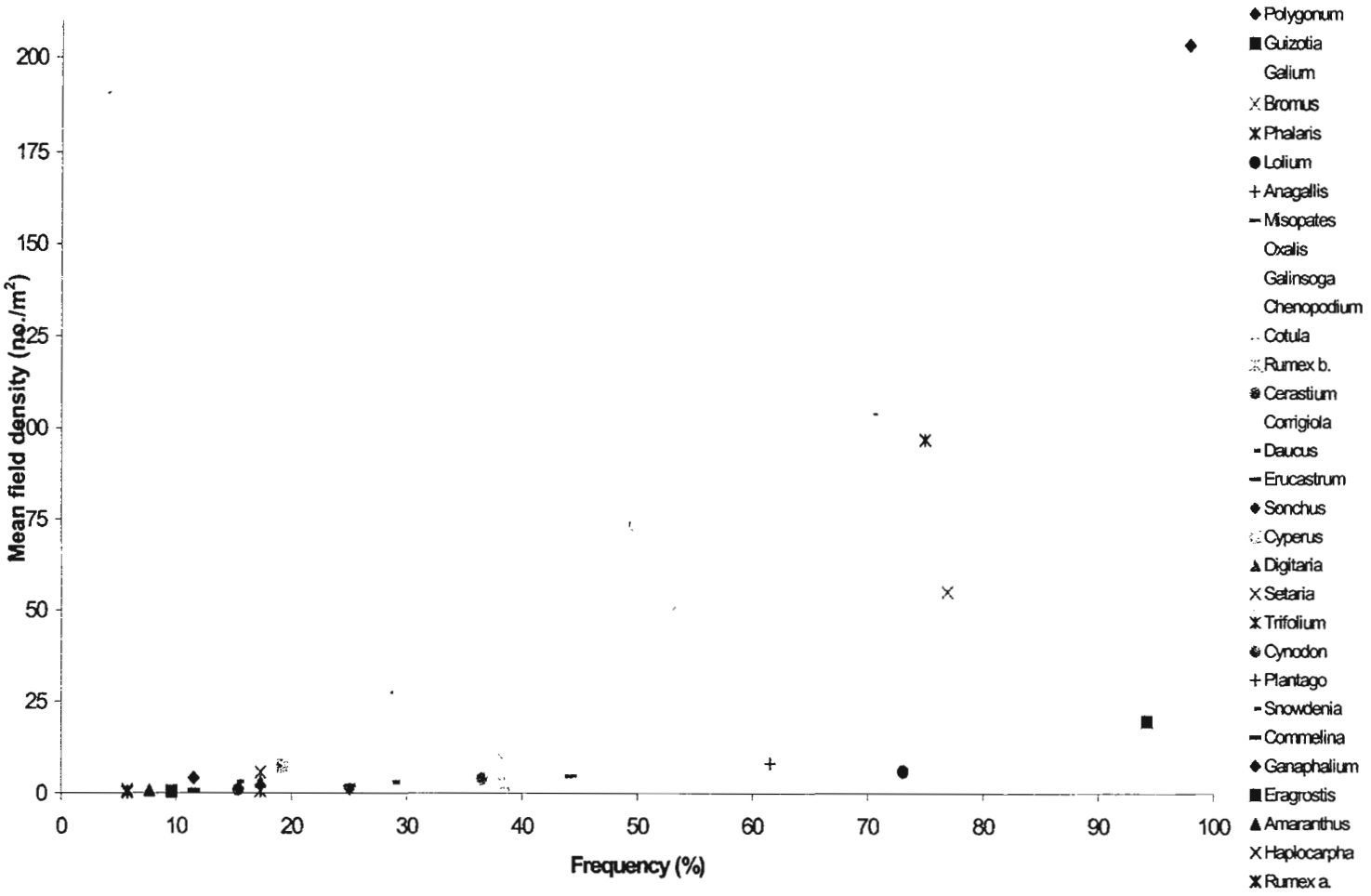

Figure 1. Scatter plot of frequency and mean field density of 31 species with frequency >5%.

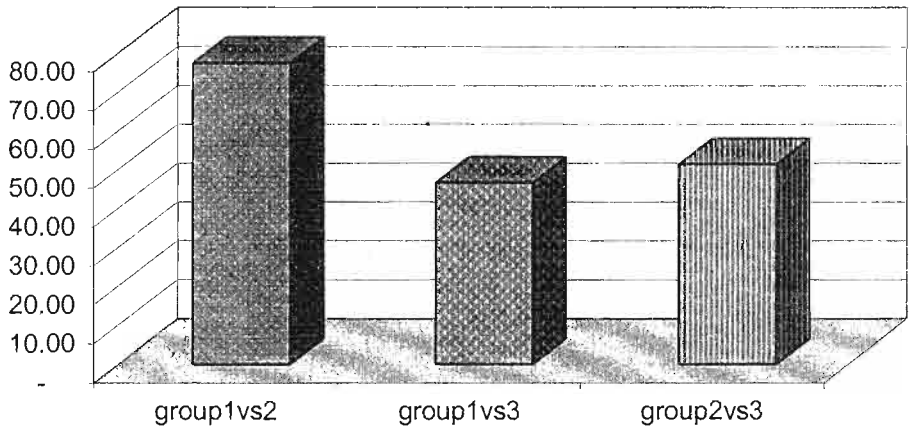

Fig. 2. Similarity indices of surveyed areas classified into three groups (1, 2 and 3 for light, black and red soils, respectively).

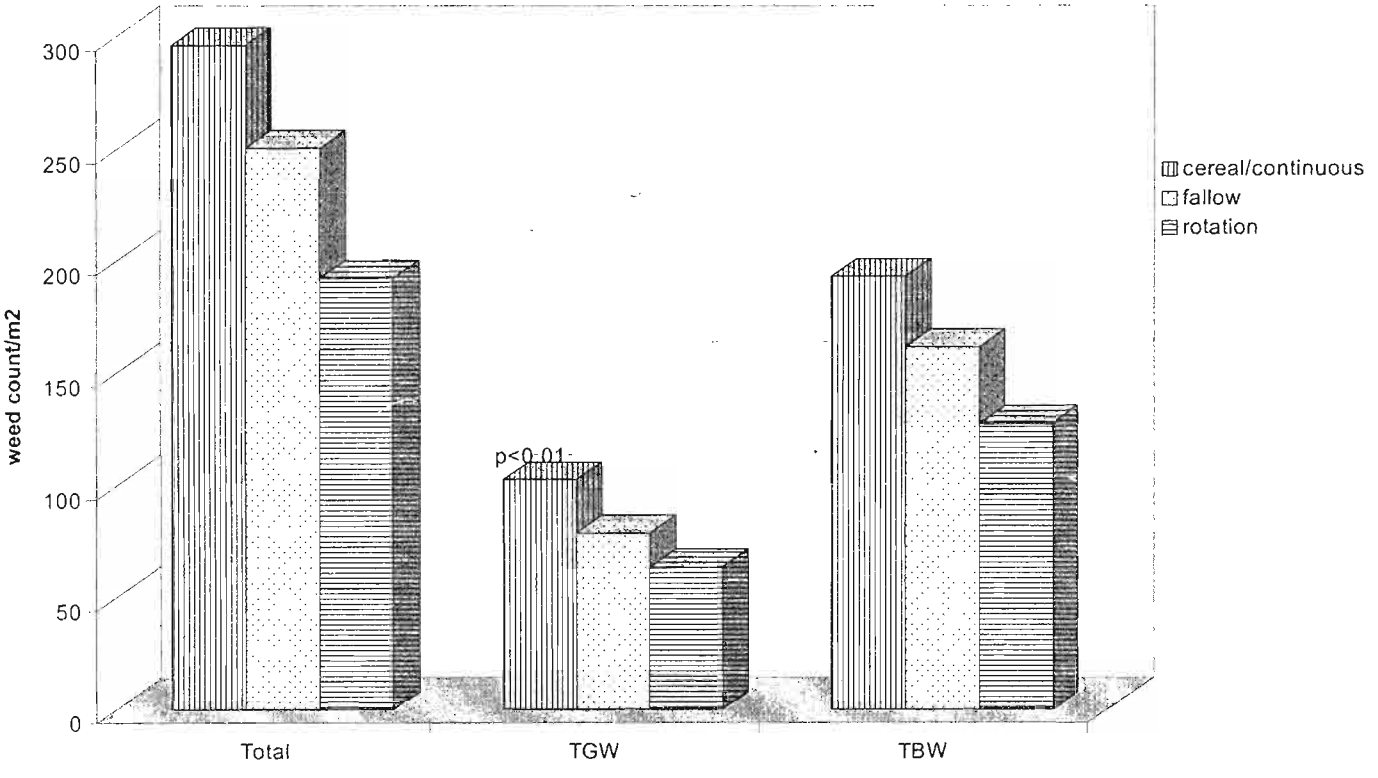

Fig. 3. The relationship between cropping system practiced by farmers and weed count data. TGW and TBW represent total grass and broadleaf weeds, respectively.

EVALUATION OF HERBICIDES FOR THE CONTROL OF BROME GRASS IN WHEAT IN SOUTH-EASTERN ETHIOPIA

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ABSTRACT

Brome grass (*Bromus pectinatus*) is a major grass weed in wheat for which no chemical control is currently available in Ethiopia. As a result, small-scale farmers suffer dramatic grain yield losses in infested fields. A weed control trial comparing two new herbicides, applied at different rates and timings, with a weedy check was conducted on seven farmers' fields in S.E. Ethiopia during the 1999 cropping season. Sulfosulfuron (post) applied at 30 g a.i. ha^{-1} resulted in 91 and 65% control of brome grass at Asasa and Etheya, respectively. The combination of sulfosulfuron (post) at 22 g a.i. ha^{-1} plus ethiozin (pre) at 1.6 kg a.i. ha^{-1} also exhibited good control of brome grass. Applying sulfosulfuron (post) at 22 g a.i. ha^{-1}, sulfosulfuron (post) at 30 g a.i. ha^{-1}, and sulfosulfuron (post) at 22 g a.i. ha^{-1} plus ethiozin (pre) at 1.6 kg a.i. ha^{-1} produced grain yield increments of 101-140% and 61-120% relative to the weedy check at Asasa and Etheya, respectively. The herbicidal chemicals sulfosulfuron and ethiozin exhibit significant potential to control problematic grass weeds including brome grass in the wheat growing areas of Ethiopia. As brome grass exhibits special adaptive characteristics such as a high rate of seed production and early maturity relative to the wheat crop, herbicidal control should not be considered as the only option. Thus, it is recommended to conduct additional research to confirm the results of this experiment and to devise an integrated approach to the control of brome grass.

INTRODUCTION

Although Ethiopian wheat producers attempt to minimize losses from weeds, grass weed species present a serious production constraint in the wheat growing areas of the south-eastern highlands. Brome grass is one such weed species that recently became prominent in the affected cropping systems due to a weed population shift attributed primarily to continuous cereal cropping and frequent use of selective herbicides against previously common grass weeds such as *Avena fatua* (Tanner and Giref, 1991; Amanuel *et al.*, 1992).

Globally, research scientists have attempted to develop herbicides to selectively control *Bromus* weed species during the last two decades (Stahlman, 1984). Metribuzin exhibited moderate control of *B. secalinus* and *B. tectorum* in wheat with a narrow window of application (Koscelny and Peeper, 1990). However, this herbicide has been ineffective for the control of *B. pectinatus* in Ethiopia (Giref, 1998). However, ethiozin applied pre-emergence at a rate of 3.6 kg a.i. ha^{-1} reduced the population of *B. pectinatus* by 39% in the field; control was reported to be 100% in a glass house screening with ethiozin applied at a rate of at least 1.3 kg a.i. ha^{-1} either pre- or post-emergence (Giref, 1998). Pre-emergence application of the

same herbicide on farmers' fields at the rate of 1.6 kg a.i. ha^{-1} achieved 68% control of brome grass (KRC, 1998). However, under specific field conditions, the population of the weed is not dramatically reduced after spraying; this might be due to a number of factors including application timing, growth stages of either the crop or the weed at the time of spraying, and/or differential impact of weather condition and soil type.

It was, therefore, considered necessary to evaluate several herbicides, including a newly introduced product, for the control of brome grass under farmers' field conditions. The new product originated from Monsanto: a sulfonyl urea compound named sulfosulfuron was reported to control *Bromus* spp. and several other grass and broadleaf weeds including *Avena fatua*, *Phalaris minor*, *Anagallis arvensis* and *Medicago polymorpha* in wheat (Monsanto, 1998). The herbicide is already marketed in the USA by Monsanto as a selective herbicide for the control of annual weeds in wheat (Koscelny *et al.*, 1997). Due to its high efficacy in controlling *Bromus* spp., further studies on the absorption and translocation of this herbicide have been carried out recently (Olson *et al.*, 1999; Miller *et al.*, 1999). The objective of the current research was to evaluate the effects of sulfosulfuron relative to other promising herbicides on brome grass and other annual weed species in bread wheat.

MATERIALS AND METHODS

Seven trials were conducted on farmers' fields in the Asasa, Bekoji, Etheya and Kulumsa districts in south-eastern Ethiopia during the 1999 cropping season. "Hotspot" sites were selected for each trial during harvest of the 1998 crop to ensure that the principal target weed (i.e., brome grass) was present in sufficient density at each site. Land preparation, sowing dates and wheat cultivars were selected according to farmers' preferences.

The weed control experiment was laid out in a randomized complete block design with three replications at each site. Eight treatments, consisting of two rates of sulfosulfuron (from Monsanto product Monitor 75 WG), pre- and post-emergence application of two rates of ethiozin (from Bayer product Tycor EC), a standard recommended treatment consisting of Puma Super + Starane M (Mohammed *et al.*, 1996), the farmers' common practice of 2,4-D application, and an unweeded check treatment were included in the trial design (Table 1). Gross plot sizes measured 5.4 by 5 m.

The wheat cultivars used were Tusie, Galama, Abolla and Wabe at Asasa, Bekoji, Etheya and Kulumsa, respectively. Wheat seed was broadcast uniformly on the land prepared by the host farmers using a seed rate of 175 kg ha^{-1}. Recommended rates of N and P_2O_5 for wheat in each district were applied in the form of urea and DAP. At planting, one-third of N and all P_2O_5 were applied; the remaining N was applied between Zadoks growth stage 22-31 (i.e., mid-tillering to stem elongation).

Pre-emergence ethiozin was applied immediately after planting of wheat by spraying the spray mix on the soil surface. Post-emergence herbicide treatments were applied at the appropriate growth stage for the crop and weeds (Table 1). Only five treatments (i.e., T1, T2, T6, T7 and T8 from Table 1) were included in the Kulumsa trial.

Weed seedling density was counted by species prior to application of post emergence herbicides 25-30 days after emergence of wheat. Wheat seedling density m^{-2}, plant height at maturity (cm), wheat spikes m^{-2} at maturity, wheat grain and biomass yields (kg ha^{-1}), thousand kernel weight (TKW) (g), and grass weed panicle density m^{-2} at crop maturity were

measured and recorded. Harvest index (HI) (%), grains per spike (no. m^{-2}) and grains per meter square (no. m^{-2}) were determined from the above measured parameters.

Before statistical analysis, weed density data were transformed using the square root of [actual count data + 0.5] to satisfy the assumptions of normality and homogeneity of variance of the data. Crop and weed data were then subjected to analysis of variance, combining the two sites for each of the three locations (i.e., excluding the Kulumsa data). Subsequently, the effects of the eight treatments in each location were partitioned into meaningful single degree of freedom components (Table 2). ANOVA of the data was performed with MSTATC statistical software, while orthogonal contrasts were calculated using Microsoft Excel in conjunction with MSTATC.

RESULTS AND DISCUSSION

Treatment effects on wheat grain yield were highly significant in all three locations (Table 3); however, not all of the treatment effects were consistent across locations. The consistent treatment effects included:

1. the low rate of sulfosulfuron (T2) performed equal to the high rate (T1) at all locations;
2. the post-emergence application of ethiozin (T5) resulted in low yields cf. the pre-emergence applications (T3 and T4);
3. the sole application of 2,4-D (T7) also resulted in low yields; and
4. the standard recommended herbicidal package (T6) resulted in low yields relative to at least one of the sulfosulfuron and/or ethiozin treatments (T1 to T4) at all locations.

The combination of ethiozin + sulfosulfuron (T3) resulted in the highest grain yields in Asasa and Etheya; however, T3 was equal in yield to T1, T2, T4 and T6 at Bekoji – the site with the highest mean density of brome grass (Table 4).

The main effect of weed control treatments was significant for all measured crop and weed parameters at one or more locations (Table 4), including wheat seedling density, wheat grain and biomass yield and spike density at maturity, total broad leaf seedling density subsequent to herbicide application, and brome grass panicle and total grass weed inflorescence density at crop maturity.

The orthogonal contrast analysis revealed a significant differential treatment effect of ethiozin applied pre-emergence vs. post-emergence on wheat seedling density at Asasa vs. Bekoji (contrast #3 in Table 4): 173 vs. 223 seedlings m^{-2} at Asasa and 204 vs. 161 seedlings m^{-2} at Bekoji. The observed decrease in seedling density at Asasa might be due to a toxic effect of ethiozin applied pre-emergence in the presence of high soil moisture levels during wheat emergence (i.e., facilitating herbicide absorption by wheat roots) (Thomson, 1993). At Bekoji, a soil with a relatively low water percolation rate cf. the sandy loam soil of Asasa, the reverse situation was observed. Within the pre-emergence applied treatments at Asasa, ethiozin at the high rate (T4) significantly reduced wheat seedling density cf. T3 (141 vs. 204 seedlings m^{-2}). This effect was also reflected in wheat spike density and crop biomass yield at maturity.

Herbicide treated plots exhibited lower mean crop heights cf. the unweeded check plots (97 vs. 105 cm) at Asasa and (107 vs. 111 cm) at Bekoji. Amanuel *et al.* (1992) reported a similar situation in which wheat height increased under competition with weeds.

Considerable difference in biomass yield of wheat was observed between treated and untreated plots. Herbicide treated plots outyielded untreated plots by 62, 19 and 68% at Asasa, Bekoji and Etheya, respectively (contrast #1 in Table 4). Plots receiving pre-emergence application of ethiozin produced higher biomass yields than post-emergence applications (contrast #3 in Table 4).

Weed control increased wheat grain yield by 72, 14 and 76% at Asasa, Bekoji and Etheya, respectively, cf. the weedy check (contrast #1 in Table 4). The standard herbicide treatment (T6) outyielded sulfosulfuron treated plots (3400 vs. 2919 kg ha^{-1}) at Etheya (contrast #2 in Table 4). This could be attributed to the superior activity of the two herbicides against a broad range of weeds at an early growth stage, thereby improving resource exploitation by the wheat crop. The significance of contrast #2 for total broad leaf weed seedling and total grass inflorescence densities at Etheya substantiates this argument: T6 significantly reduced total broad leaf and grass weed populations cf. the sulfosulfuron treatments – despite a significant decrease of brome grass populations by sulfosulfuron cf. T6. Thus, wheat grain yields responded to differences in the weed flora at each location, and to differential responses of the respective flora to the applied weed control treatments.

Pre-emergence application of ethiozin exhibited superior control of brome grass density at Bekoji and total grass weed density at Bekoji and Etheya (contrast #3 in Table 4). This differential effect was reflected in a 22-49% grain yield advantage for pre-emergence ethiozin cf. post-emergence application across the three locations (contrast #3 in Table 4).

A significant difference in wheat spike density at maturity was observed between the unweeded vs. herbicide treated plots (295 vs. 349 spikes m^{-2} at Asasa and 203 vs. 262 spikes m^{-2} at Etheya) (contrast #1 in Table 4).

Broad leaf weed seedling densities were reduced 10 days after herbicide application by 53% at Asasa, 52% at Bekoji, and 57% at Etheya. Obviously, broad leaf weed densities differed between the unweeded check and herbicide treated plots (contrast #1 in Table 4). The broadleaf herbicide included in T6, Starane M, demonstrated superior control of broad leaf weeds cf. sulfosulfuron alone which was reputed to be effective against a range of grass and broad leaf weed species (contrast #2 in Table 4). Apparently, the activity of sulfosulfuron on broadleaf weeds was lower than indicated on the product label (Monsanto, 1998).

Brome grass panicle counts at maturity exhibited highly significant effects of herbicides (Table 4). The panicle density of brome grass was markedly lower in the sulfosulfuron treated plots cf. plots treated with Puma Super + Starane M at Bekoji and Etheya (contrast #2 in Table 4). Also, the combination of sulfosulfuron + ethiozin (T3) significantly reduced brome grass panicle density compared with the unweeded cheek. Therefore, pre-emergence application of ethiozin exhibits potential for the control of brome grass infestation. In general, across locations and sites, sulfosulfuron reduced the panicle density of brome grass by 47% cf. the weedy check. Weed count data 10 days after herbicide application revealed that sulfosulfuron at the high rate (T1) reduced brome grass density by 91% at Asasa and 65% at Etheya. Correlation analysis revealed a strong negative relationship between wheat grain yield and brome grass density at Etheya ($r = -0.48$, $P<0.01$).

Puma Super + Starane M (T6) exhibited superior control of total grass weed infestation cf. sulfosulfuron (contrast #2 in Table 4), reflecting the ability of Puma Super to control the

other common grass weed species in the testing sites such as *Setaria pumila* and *Phalaris minor* (Amanuel *et al.*, 1992). Pre-emergence applied ethiozin also showed good control of the total grass weed population. However, since the experiment was conducted on-farmers' fields under natural infestations, there were several flushes of weeds emerging throughout the crop cycle; thus, an apparently poor percent control of the weed may not reflect the actual efficacy of a post-emergence applied herbicide.

CONCLUSIONS

The herbicidal chemicals sulfosulfuron and ethiozin exhibit significant potential to control problematic grass weeds including brome grass in the wheat growing areas of Ethiopia. As brome grass exhibits special adaptive characteristics such as a high rate of seed production and early maturity relative to the wheat crop, herbicidal control should not be considered as the only option. Thus, it is recommended to conduct additional research to confirm the results of this experiment and to devise an integrated approach to the control of brome grass.

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Table 1. Treatments included in the on-farm trials.

Tr. #	Common name(s)	Rate(s) (kg a.i. ha^{-1})	Time of application
1	sulfosulfuron	0.03	Post (1-4 leaf)
2	sulfosulfuron	0.0222	Post (1-4 leaf)
3	ethiozin + sulfosulfuron	1.6 + 0.0222	Pre + Post (1-4 leaf)
4	ethiozin + 2,4-D	1.9 + 0.72	Pre + Post (3-5 leaf)
5	ethiozin + 2,4-D	1.6 + 0.72	Post (2-4) + Post (3-5)
6	fenoxaprop-p-ethyl + fluroxypyr + MCPA	0.069 + 0.07 + 0.4	Post (1-4 leaf)
7	2,4-D	0.72	Post (3-5 leaf)
8	Weedy check	-	-

Table 2. Orthogonal contrast coefficients used in the treatment comparisons.

Contrast:	#1	#2	#3
Tr.#	Herbicides vs. Unweeded	sulfosulfuron vs. Tr.#6	ethiozin pre vs. ethiozin post
1	1	1	0
2	1	1	0
3	1	0	1
4	1	0	1
5	1	0	-2
6	1	-2	0
7	1	0	0
8	-7	0	0

Table 3. Effect of treatments on grain yield (GY) at Asasa, Bekoji and Etheya sites.

	Asasa		Bekoji		Etheya	
Treatment	GY (kg/ha)	GYI[a] (%)	GY (kg/ha)	GYI[a] (%)	GY (kg/ha)	GYI[a] (%)
1	3062 AB	107	3622 A	18	2920 BC	62
2	2970 B	101	3641 A	19	2919 BC	61
3	3540 A	140	3642 A	19	3980 A	120
4	1973 CD	33	3840 A	25	3912 A	116
5	2149 C	45	3068 C	0	2646 C	46
6	2791 B	89	3486 AB	14	3400 AB	88
7	1309 E	-11	3157 BC	3	2468 C	37
8	1478 DE	-	3065 C	-	1808 D	-
Mean	2409		3440		3007	
$LSD_{(0.05)}$	556.3		395.5		643.9	
C.V.(%)	19.5		9.7		18.1	

Means followed by same letter are not significantly different at the 5% level of LSD test.
[a] Relative to weedy check.

Table 4. Results of ANOVA and orthogonal contrast analyses.

Parameter	Treatment effect			Contrast[b]								
				#1			#2			#3		
	A	B	E	A	B	E	A	B	E	A	B	E
Seedlings m^{-2}	**	NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS
Mean	213	188	220							173	204	
C.V.(%)	17.8	18.0	16.7							vs. 223	vs. 162	
BY (kg ha^{-1})	***	**	**	***	*	***	NS	NS	NS	*	***	***
Mean	7350	10602	8118	7720	10814	8551				8159	12205	10601
C.V.(%)	16.7	13.9	17.9	vs. 4755	vs. 9116	vs. 5089				vs. 6817	vs. 9467	vs. 7406
GY (kg ha^{-1})	***	**	***	***	**	**	NS	NS	$P<0.1$	*	***	***
Mean	2409	3440	3007	2542	3494	3178			2920	2757	3741	3946
C.V.(%)	19.5	9.7	18.1	vs. 1478	vs. 3065	vs. 1808			vs. 3400	vs. 2149	vs. 3068	vs. 2646
Spikes m^{-2}	**	NS	$P<0.1$	*	NS	**	NS	NS	NS	NS	NS	NS
Mean	342	304	254	349		262						
C.V.(%)	14.4	14.2	18.6	vs. 295		vs. 203						
TBLW[a]	***	***	***	***	***	*	***	***	***	NS	NS	NS
Mean	4.48	6.58	7.09	4.21	6.09	6.50	6.58	8.89	10.74			
C.V.(%)	37.4	27.7	21.4	vs. 6.14	vs. 9.95	vs. 11.2	vs. 2.80	vs. 4.87	vs. 6.11			
BPEC[a]	***	***	***	NS	NS	NS	NS	***	**	NS	**	NS
Mean	1.52	4.31	2.30					3.64	2.26		2.50	
C.V.(%)	22.1	32.3	39.5					vs. 6.88	vs. 3.67		vs. 4.95	
TGI[a]	*	$P<0.1$	**	NS	NS	NS	NS	NS	*	NS	*	$P<0.1$
Mean	3.25	9.61	6.95						7.28		8.29	6.05
C.V.(%)	9.5	17.6	17.4						vs. 5.90		vs. 10.52	vs. 7.18

$P<0.1$, *, **, *** Indicate significance at the 10, 5, 1 and 0.1% probability levels, respectively; NS = Not significant ($P>0.1$).
GY = wheat grain yield; BY = wheat biomass yield; TBLW = total broadleaf weed density m^{-2} 10 days after spraying; BPEC = *Bromus pectinatus* panicle density m^{-2} at maturity; TGI = total grass weed inflorescence density m^{-2} at maturity; A = Asasa; B = Bekoji; E = Etheya.
[a] Transformed by square root of [weed count m^{-2} + 0.5].
[b] See Table 3 for corresponding orthogonal contrast.

EVALUATION OF THE EFFECTS OF SURFACE DRAINAGE METHODS ON THE YIELD OF BREAD WHEAT ON VERTISOLS IN ARSI ZONE

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ABSTRACT

An experiment was conducted to investigate and confirm the effect of different surface drainage methods on the yield of bread wheat on Vertisols at two locations in Arsi Zone of south-eastern Ethiopia for three consecutive years. The experiment compared two surface drainage methods, ridge and furrow (RF) and broad bed and furrow (BBF), with a flat seedbed (control). The combined statistical analysis over years revealed that, at Sagure, grain yield increases of about 1200 and 690 kg/ha were obtained using BBF and RF surface drainage methods, respectively. Similarly, at Arsi-Robe, grain yield increases were 660 and 300 kg/ha over the control treatment using BBF and RF surface drainage, respectively. Straw yields were influenced in a similar manner. Furthermore, the use of BBF reduced the time taken to cover the seed at sowing significantly (11.6 hr/ha), followed by RF (22.9 hr/ha), as compared to the flat seedbed (42.3 hr/ha). The overall assessment of surface drainage methods ranks BBF first for the parameters considered in this study. The current result confirmed earlier findings in central Ethiopia.

INTRODUCTION

In Ethiopia, Vertisols cover about 12.6 million ha of land of which about 13% are found in south-eastern part of the country (Bull, 1987). These soils have great potential for crop production since they are located mainly in the highlands where there is reliable rainfall and intensive farming. The south-eastern parts of the country in general and Arsi zone in particular are among the most important areas for bread wheat production. However, due to the inherent characteristics of these soils coupled with high rainfall, yield is low mainly due to waterlogging. Waterlogging results in poor aeration, lower soil microbial activities, loss and unavailability of plant nutrients and poor agricultural workability (Trough and Drew, 1982; Tesfaye *et al.*, 1991).

According to Trough and Drew (1982), within two days, even at low temperature, available oxygen can be totally removed from the profile of waterlogged soil. Moreover, nitrogen availability can be seriously lowered in waterlogged soils due to denitrification caused by anaerobic soil bacteria (Belford *et al.*, 1985; Cook and Veseth, 1991).

The root tips, where most water, air and nutrient uptake takes place, are the first to suffer from waterlogging mainly due to lack of oxygen reducing the seminal root growth in particular (van Ginkel *et al.*, 1991). As a result of this, the crop roots are poorly aerated and nutrient uptake for growth and development will be impaired (McDonald and Gardner, 1987). Waterlogging during tillering and stem elongation leads to fewer tillers, more floral sterility, fewer grains per spike, reduced kernel weight and a final yield loss of 50% or more (Grieve *et*

al., 1986; McDonald and Gardner, 1987). Thus, wheat production on Vertisols is constrained by the physical and hydrological properties of these soils.

Farmers in Ethiopia generally use different traditional methods to improve the drainage situation of these soils since antiquity. These include, soil burning "guie" followed by a long period of fallowing after cropping, late planting (i.e., at the end of the main rain season) using a furrow with a certain interval after planting or left for grazing (native pasture) because of severe drainage problems (ARDU, 1983). Such traditional soil, water and crop management practices have their own side effects due to decrease in soil fertility in the case of soil burning and terminal drought stress in case of late planting (Mesfin *et al.*, 1991).

In order to alleviate this continued problem, various surface and sub-surface drainage methods such as camberbed, clay tiles, eucalyptus or bamboo poles were tested and found to be effective in raising the grain yield of wheat in Arsi Zone (ARDU, 1983). However, despite their effectiveness, the adoption of these technologies by subsistence farmers was limited. This is due to the cost of the materials which require high capital investment and inconvenience to implement some of the methods due to the fragmented nature of the farmers' land holding system as well (Tesfaye *et al.*, 1991).

Cultivars are the easiest technology to be adopted by subsistence farmers. However, it was recommended that complementary contributions of improved soil and water management practices that improve the drainage of Vertisols and offer an opportunity for early planting and thereby increase yield are essential (Hiruy, 1986; Tesfaye *et al.*, 1991). Furthermore, it has been reported that removal of excess water from Vertisol sites enhance significantly the response of wheat to fertilizer application (Asnakew *et al.*, 1991; Belford *et al.*, 1985).

Therefore, the previously developed technology (BBF) by ILCA, now ILRI, which was found to be effective in the central part of Ethiopia was tested in Arsi Zone considering the greater physico-chemical heterogeneity of the soil and environment into account. This paper presents the effects of two surface drainage methods in comparison with flat seedbed on the different crop parameters of bread wheat under Vertisol conditions in Arsi Zone of south-eastern Ethiopia.

MATERIALS AND METHODS

The experiment was conducted in Arsi Zone of south-eastern Ethiopia particularly at Arsi-Robe (2420 m a.s.l.) and Sagure (2450 m a.s.l.) for three consecutive years starting from 1993. Table 1 indicates the physico-chemical characteristics of the respective sites.

The experiment encompassed two different surface drainage methods: Ridge and Furrow (RF), draining the excess water through the furrow while the crops are grown on the ridge; Broadbed and Furrow (BBF) developed by ILCA (Jutzi *et al.*, 1987) which permits wheat seedlings to grow on the bed of 80 cm width and 20 cm furrow for water drainage. The flat seedbed was considered as a control. The plot size was 10 m by 9.8 m and the trial was laid out in a RCBD with three replications. The bread wheat variety ET-13 was used at a seed rate of 175 kg/ha together with application of 82-20 kg N-P per ha. Planting was done in the main season at the start of rain each year and for each location before soils become too wet. In 1995, the time taken to cover the seed was recorded for each treatment and site. Weeds were controlled with herbicides. After maturity, plant height was measured and harvesting was done from an area of 9 m^2 by sickles just above ground level. Then, biomass and grain yield

was recorded and the grain yield was adjusted to 12.5% moisture content before statistical analysis. Eventually, data were subjected to statistical analysis using the MSTATC statistical package, and differences between means were separated by the LSD test at the 0.05 level if significant treatment effects occurred.

RESULTS AND DISCUSSION

The first year (1993) results indicate, as apparently seen in Table 2, significant differences in grain yield both at Sagure and Arsi-Robe with a grain yield advantage of 1580 kg/ha (+122%) and 560 kg/ha (+56.9%), respectively, for broad bed and furrow (BBF) over the flat seedbed. At Sagure, the straw yield was significantly higher, 1450 kg/ha (+29%), for the BBF plots than the flat seedbed. Likewise, significantly taller plant height, 20.3 cm (+22.1%) and 9 cm (+11.5%) was recorded from BBF plots than the flat seedbed at Sagure and Arsi-Robe, respectively. This higher plant height from BBF plots contributed to the straw yield increase. Moreover, the BBF drainage method increased plant height by 12 cm (12%) over the RF. Even though there were increases in straw and grain yield from BBF plots over the ridge and furrow (RF) drainage method at both locations, the difference was significant only for grain yield at Arsi-Robe (Table 2).

During the 1994 cropping season at Arsi-Robe, as shown in Table 3, a grain yield advantage of 460 kg/ha (+98%) and 220 kg/ha (+46.8%) were obtained due to BBF and ridge and furrow, respectively, over the flat seedbed. During the same cropping season, the result at Sagure indicate a significant variation in grain yield with an additional yield of 1290 kg/ha (+137%) and 610 kg/ha (+64.9%) using BBF and RF drainage methods in comparison with the flat seedbed, respectively. Although there was an increase in straw yield at both locations for BBF and RF, the result was not significant. A higher plant height, 13.3 cm (+24.2%), was recorded from BBF plots relative to the flat seedbed at Arsi-Robe. Similarly additional plant height of 8.7 cm (+9.7%) and 4.7 cm (+5.2%) was recorded from both BBF and RF drainage methods, respectively over the flat seedbed at Sagure (Table 3).

Furthermore, in 1995 an extra grain yield of 940 kg/ha (+96.8%) was obtained using BBF as compared with the flat seedbed at Arsi Robe. At Sagure, the grain yield advantage was 620 kg/ha (+40.4%) and 320 kg/ha (+20.4%) using BBF and RF drainage methods, respectively, relative to the flat seedbed. The straw yield was significant during this season, with an increase of 4190 kg/ha (+162%) and 3130 kg/ha (+102%) at Arsi Robe and 4355 kg/ha (+186%) and 1940 kg/ha (+82.1%) at Sagure using BBF and RF drainage methods, respectively, compared with the flat seedbed. Moreover, significantly higher plant height was recorded from BBF plots which was 15.4 cm (+18.9%) and 17 cm (+18.4%) over the flat seedbed at Arsi Robe and Sagure, respectively.

Interestingly, the combined statistical analysis over years (Table 5) revealed that an extra grain yield of about 1200 kg/ha and 700 kg/ha over the control treatment were obtained using BBF and RF surface drainage methods at Sagure, respectively. Likewise, grain yield increases of 660 kg/ha and 170 kg/ha in comparison with the control treatment were obtained using BBF and RF surface drainage methods at Arsi-Robe, respectively.

The higher clay content, relatively level gradient and inherent poor soil fertility at Arsi-Robe than Sagure (Table 1) basically elucidate the lower yield in the former location. Even though grain yield was generally low at this location, the result obtained with BBF was encouraging and significantly improved.

Moreover, in 1995, the time taken to cover the seed was recorded in both locations. The combined statistical analysis result over locations indicated that, significantly, a very low time (11.6 hr/ha) was needed to cover the seed using BBF as compared to RF (22.9 hr/ha) and 42.3 hr/ha for the control. Thus, by reducing the time required for seed covering at planting, the BBF method gives opportunity for the farmer to participate in other activities. The current finding is in agreement with results obtained in other parts of the country (Mesfin *et al.*, 1991). Therefore, the promising treatments, particularly BBF, can be used by farmers in Arsi Zone.

CONCLUSION

The attempt made to drain the excess water improved bread wheat yield. The outcome of the experiment is in agreement with results obtained in other parts of the country. The overall assessment of the drainage methods puts BBF on top of the other treatments with regard to grain and straw yields obtained at both locations. The BBF was also the most efficient method to cover the seed at planting in waterlogged soils. Therefore, in waterlogged soils, use of an efficient drainage method such as BBF would help to improve grain and straw yield thus allowing integrated crop and livestock production.

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Questions and Answers:

Mamoun I. Dawelbeit: What are the types of implements used for seeding and bed formation?

Answer: A chain attached to the broadbed maker is used to cover the seed after broadcasting. The broadbed maker (BBM) is used to make the bed.

Table 1. The physico-chemical characteristics of the top soil (0-30 cm) and rainfall data for the different years and respective sites.

Location	Year	Soil characteristics							Rain-fall (mm)
		Soil texture (%)			OM (%)	N (%)	P (ppm)	pH	
		Sand	Silt	Clay					
Arsi-Robe	1993	8.9	34.3	56.7	6.6	0.25	16	5.8	413
	1994	7.0	35.2	57.8	6.7	0.24	15	5.7	-
	1995	11.8	27.9	60.3	6.6	0.25	16	5.9	495
Sagure	1993	17.7	39.8	42.5	9.9	0.54	9	5.9	409
	1994	18.6	36.0	45.4	9.7	0.53	10	5.6	578
	1995	18.4	32.1	49.5	9.8	0.55	10	5.7	529

OM = Soil organic matter; N = Total nitrogen; P = Available phosphorus; and Rainfall = Total rainfall from June-Sep.

Table 2. The effects of surface drainage methods on different crop parameters of bread wheat at Sagure and Arsi-Robe Vertisol sites in 1993.

Treatment	Location					
	Sagure			Arsi-Robe		
	GRY	STY	PLHT	GRY	STY	PLHT
Flat seedbed	1296A	5003A	91.7A	986A	3353A	78.3A
RF	2388B	5330AB	100.3B	1112B	3588A	81.7AB
BBF	2876B	6456B	112C	1547C	4018A	87.3B
Mean	2186	5596	101.3	1215	3653	82.4
LSD (0.05)	705	1196	3.94	197	NS	5.9
C.V.(%)	16.15	10.7	1.95	8.13	13.18	3.64

Means in a column followed by a common letter are not significantly different from each other at the 5% level of the LSD test.
NS = Non-significant; GRY = Grain yield (kg/ha); STY = Straw yield (kg/ha); PLHT = Plant height at harvest (cm); RF = Ridge and furrow; and BBF = Broadbed and furrow.

Table 3. The effects of surface drainage methods on different crop parameters of bread wheat at Sagure and Arsi-Robe Vertisol sites in 1994.

Treatment	Location					
	Sagure			Arsi-Robe		
	GRY	STY	PLHT	GRY	STY	PLHT
Flat seedbed	941A	2593A	90A	466A	4048A	55A
RF	1552B	2600A	94.7B	684B	4074A	63.7B
BBF	2231C	2808A	98.7C	923C	4113A	68.3B
Mean	1575	2667	94.4	690	4078	62.3
LSD (0.05)	474	NS	3.20	208	NS	6.4
C.V.(%)	15.08	19.41	2.18	15.05	3.77	5.13

See Table 2 for definitions.

Table 4. The effects of surface drainage methods on different crop parameters of bread wheat at Sagure and Arsi-Robe Vertisol sites in 1995.

Treatment	Location					
	Sagure			Arsi-Robe		
	GRY	STY	PLHT	GRY	STY	PLHT
Flat seedbed	1546A	2339A	92.3A	976A	2587A	81.3A
RF	1861B	4274B	104.7B	1148A	4509B	92.0B
BBF	2171C	6694C	109.3C	1921B	6777C	96.7B
Mean	1859	4436	102.1	1348	4624	90
LSD (0.05)	168	479	3.83	314.5	595	9.7
C.V.(%)	4.53	5.41	1.88	11.67	6.44	5.39

See Table 2 for definitions.

Table 5. The combined statistical analysis over years for the different drainage methods on the various crop parameters (1993-1995).

Treatment	Location					
	Sagure			Arsi-Robe		
	GRY	STY	PLHT	GRY	STY	PLHT
Flat seedbed	1263A	3312A	91.3A	809A	3329A	71.6A
RF	1956B	4068B	99.9B	982B	4057B	79.1B
BBF	2458C	5320C	106.7C	1464C	4969C	84.1C
Mean	1892	4233	99.3	1085	4119	78.3
LSD (0.05)	199	372	5.71	101	316	2.66
C.V.(%)	10.24	8.56	1.62	9.06	7.47	3.31

See Table 2 for definitions.

Table 6. The time taken to cover wheat seed at planting for the different drainage methods (hr/ha).

Treatment	Sagure	Arsi-Robe	Over-Locations
Flat seedbed	38.89A	45.8A	42.32A
RF	22.22B	23.5B	22.88B
BBF	10.05C	13.2C	11.64C
Mean	23.72	27.5	25.61
LSD (0.05)	3.468	3.03	3.486
C.V.(%)	7.32	5.53	11.06

Means in a column followed by a common letter are not significantly different from each other at the 5% level of the LSD test. NS = Non-significant.

CROP ROTATION EFFECTS ON GRAIN YIELD AND YIELD COMPONENTS OF BREAD WHEAT IN THE BALE HIGHLANDS OF SOUTH-EASTERN ETHIOPIA

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ABSTRACT

Rotation of alternate crops with bread wheat was studied at the Sinana R.C. using six precursor crops and two rates of fertilizer, viz., 9-23 and 41-46 N-P_2O_5 kg/ha, applied to precursors and wheat. The break crops, viz., bread wheat, barley, emmer wheat, faba bean, field pea and linseed, were grown in the gena season of 1996 and bona of 1995 and 1997, while the main bread wheat crop was grown during alternate years in the gena season of 1997 and bona of 1996 and 1998 in separate fields for each season. Bread wheat after pulses produced a higher grain yield cf. after cereals with a yield advantage of 8-14%. This advantage was higher in 1998 than 1996 implying a gradual increase in the effect of rotation. Kernels m^{-2} was the most important yield component contributing about 94.6% of the variation in grain yield. Fertilizer rate had a significant effect on grain yield, kernels m^{-2}, kernels and yield per spike, harvest index, and straw yield during bona 1998. In general, pulses are beneficial break crops in contrast to continuous cropping of cereals. It is important to investigate the long-term effects of rotation and to extend the study to farmers' fields.

INTRODUCTION

Crop rotation, growing a sequence of plant species on the same land (Yates, 1954) is in contrast to the growing of the same species repeatedly on the same land (Power, 1990). It can maintain crop yields by controlling weeds, insects, and disease and preventing soil erosion. Crop rotation mostly maintains soil fertility through supplying nitrogen (Bullock, 1992).

Bread wheat and barley are the most adapted and the main staple food and income generating crops. Wheat is grown extensively by peasant farmers and state farms in the highlands of Bale. Mostly they rotate bread wheat with barley and sometimes with emmer wheat and linseed. Such a high proportion of cereal after cereal can result in yield reduction, particularly where soil fertility and weed control practices are sub-optimal and soil borne diseases are common (Tanner *et al.*, 1991).

In Bale highlands, currently, monoculture of wheat or barley is the dominant practice. Farmers practice rotation of cereals or application of small amount of fertilizer on low fertile soils. These practices have a significant negative effect on yield from time to time due to deterioration of soil fertility. Even though farmers are conscious of the problem, they have no access to use proper fertilization. Hence, using leguminous crops as a favorable break crop may be one of the possible solutions for wheat production in the zone. Tanner *et al.* (1991)

found that faba bean, field pea and linseed in that order are the best beneficial break crops in wheat production. Therefore, a crop rotation experiment was conducted on bread wheat to evaluate the effect of different break crops on the grain yield and yield components of bread wheat; and to determine the most beneficial precursor crop in wheat production.

MATERIALS AND METHODS

Treatments and Experimental Design

A crop rotation study was executed for bread wheat at Sinana on-station during bona (meher) (August to December) season of 1995-98 and gena (belg) (April to August) of 1996 and 1997 seasons on two separate fields for each season. Precursors were grown during gena 1996 and bona 1995 and 1997 seasons while the principal crop was grown in alternate years i.e. gena 1997 and bona 1996 and 1998 seasons.

The treatments were laid out in a randomized complete block design with three replications. Six precursor crops, bread wheat, barley, emmer wheat, faba bean, field pea and linseed, and two rates of fertilizer, 9-23 and 41-46 N-P_2O_5 kg/ha, were sown each on a plot size 20 m^2 having 20 rows of 5 m length. The distance between the rows was 20 cm. Urea and DAP were used as sources of fertilizer. Similar fertilizer rate was applied on both precursor and principal crop to minimize the variation of soil fertility. The arrangement and rates were repeated up to the end of the project. The experimental land was ploughed by tractors and row planting was made manually. Sowing dates ranged between mid August to early September. The variety ET-13 was used as a principal crop. The treatments were shown in Table 1.

Data Collection and Measuring Methods

At maturity, plant height, productive spikes m^{-2}, and spike length were measured. Fourteen central rows of 5 m length (14 m^2) was harvested manually to measure grain and biomass yield. Thousand-kernel weight was measured from the sample grain yield. Harvest index was calculated from grain and biomass yields. The other parameters were calculated in the following steps: (1) grain yield (g) $spike^{-1}$ = (grain yield (kg ha^{-1})/10)/(spikes m^{-2}); (2) kernel $spike^{-1}$ = (1000 kernels/weight of 1000 kernels (g)*yield $spike^{-1}$ (g); (3) kernels m^{-2} = (kernels $spike^{-1}$)*(spikes m^{-2}); and (4) straw yield (kg/ha) = biomass yield (kg/ha) - grain yield (kg/ha).

Statistical Analysis of Agronomic Parameters

Data were subjected to analysis of variance using MSTATC microcomputer software. Parameters of the principal crop were analyzed each year separately. Treatment degrees of freedom (df) and total sum of squares of precursor were partitioned by orthogonal contrasts into 5 meaningful single df components for each parameter. The major groups are:

1. Pulses vs. cereals and linseed
2. Cereals vs. linseed
3. Within cereal group, wheat vs. barley
4. Within wheat, bread wheat vs. emmer wheat
5. Within pulses, faba bean vs. field pea

Only those parameters with significant partitioned group were presented in the orthogonal contrast table.

Using multiple linear correlation and regression model and step wise method parameters with significant partial coefficient of regression and better contribution to the variation of grain and straw yield, yield/spike and kernel m^{-2} were selected and used in the model (Rangaswamy, 1995). The contribution of each independent terms to the variations of dependent variables in the model was calculated as: $\% bi = (\beta i^2 / \sum \beta i^2) * 100$, where bi and βi are sample regression coefficient and standard partial regression coefficient of each independent variables, respectively whereas i is the independent variable.

RESULTS AND DISCUSSIONS

Grain Yield

There was no significant effect of precursor crops on grain yield in all of the seasons. However, the partitioning of the main effect of precursors into single df as pulses vs. cereals and linseed indicated that wheat sown after pulses gave higher grain yield than after others in both bona 1996 and 1998 (Tables 2 and 3). Pulses vs. others contributed about 47.2 and 66.1 % of the total precursor sum of square in the respective years of bona season. Wheat grown after pulses had yield advantages of 243.5 kg/ha (7.4%) and 480 kg/ha (13.3%) over wheat after cereals in 1996 and 1998 bona season, respectively. This implied that pulse precursor had more effect on grain yield in 1998 than 1996. This gradual and sustainable effects of crop rotation might be through supplying more nitrate in the soil after pulses (Amanuel *et al.*, 1996). The benefit of pulses in this finding agrees with the findings of Tanner *et al.* (1991 & 1998) and Mooleki and Siwale (1998).

Fertilizer rate had a significant effect on grain yield during bona 1998. This might indicate the reduction of soil fertility over time with the application of the lower fertilizer rate. Application of 41-46 N-P_2O_5 kg/ha gave a yield advantage of 558 kg (16%) over 9-23 N-P_2O_5 kg/ha in 1998 (Tables 2 and 5).

Kernels per unit area and 1000-kernel weight were strongly associated with grain yield per hectare (Table 6). Kernels per unit area contributed about 94.6% to the variation of grain yield, the most important yield component. The effect of precursor crops and fertilizer rates on different agronomic parameters played a significant role in the increment of grain yield per unit area.

Yield Components

Precursor crops had significant effects on spikes and kernels m^{-2} in bona 1996 (Table 3). However, the partitioning of main effect of precursors into single df component of pulses vs. cereals & linseed affected kernels and spikes m^{-2} during bona 1996 and 1998, and yield and kernel per spike during bona 1998. Linseed vs. cereal component had also significant effect on yield and kernels per spike during gena 1997 (Table 3). Pulses had higher effect than others on kernels and spikes m^{-2} while both pulses and linseed had greater effect on yield and kernels per spike. The effect of linseed and pulses on kernels per spike of main crop was manifested on yield per spike as it was strongly correlated to yield per spike (Table 6).

Fertilizer application increased kernels and spikes m^{-2}, yield and kernels per spike during bona 1998 (Table 5). Productive spikes per unit area and kernels per spike were strongly associated with kernels per unit area. Kernels per spike contributed about 80.4% to the variation of kernels per unit area. The effect of precursors or fertilizer rate on kernels per unit area was due to their effect during tillering and kernel growth or both simultaneously. Kernels per spike played a significant role in the variation of both yield per spike and kernels per unit area.

Straw Yield, Plant Height, and Harvest Index

Precursor crops had no effect on straw yield, plant height and harvest index. However, the partitioned main effect of precursors into single df component of pulses vs. cereals & linseed showed that bread wheat grown after pulses gave higher straw yield than after other crops in bona 1996 and 1998 (Table 3). It contributed about 46.7 and 62.3% of the total sum of square of precursor during the respective years, which indicated the gradual advantage of pulse precursors in increasing the straw yield of the principal crop.

Fertilizer rates had significant effects on straw yield and plant height during bona 1996 and 1998 and on harvest index during 1996. The application of 41-46 N-P_2O_5 kg/ha gave higher straw yield and taller plants and lower harvest index than 9-23 N- P_2O_5 kg/ha (Table 5). Straw yield was linearly and positively associated with plant height (Table 6), which showed that the enhancement of plant height or vegetative growth might increase photosynthetic area and finally straw yield.

In general, pulses are the most beneficial break crops. The effect of both precursors and fertilizer rate on grain yield and yield components were observed gradually. Therefore, long-term investigation of rotation effect under Sinana condition and extending the recommendation to the user is essential.

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Table 1. Management practices for precursor crops.

	Crop	Variety	Seed rate (kg/ha)	Fertilizer rate (kg/ha)
1	Bread wheat	ET-13	150	9-23 and 41-46
2	Barley	Aruso (local)	100	9-23 and 41-46
3	Emmer wheat	Local	150	9-23 and 41-46
4	Faba bean	CS-20DK	200	9-23 and 41-46
5	Field pea	G-22763-2c	150	9-23 and 41-46
6	Linseed	CI-1652	25	9-23 and 41-46

Table 2. Analysis of grain yield of bread wheat after different precursor crops during gena 1997 and bona 1996 and 1998, Sinana.

Source of variation	d.f.	MS	F	Prob.
	Bona (meher) 1996			
Precursor	5	192870	2.1	>1
Pulses vs. others	1	474372	5.2	<0.05
Others	4	122494	1.3	NS
Fertilizer	1	94219	0.03	NS
Precursor X fertilizer	5	159463	1.7	NS
Error	22	159463		
	Gena (belg) 1997			
Precursor	5	145662	1.5	NS
Pulses vs. others	1	312050	3.3	NS
Others	4	1338753	1.5	NS
Fertilizer	1	98073	1.13	NS
Precursor X fertilizer	5	29339	0.33	NS
Error	22	95879		
	Bona (meher) 1998			
Precursor	5	557424	3.2	NS
Pulses vs. others	1	1843200	10.6	<0.001
others	4	235979	1.4	NS
Fertilizer	1	2809976	29.56	<0.001
Precursor X fertilizer	5	290787	3.06	0.052
Error	22	173974		

Table 3. Orthogonal contrast for grain yield and other agronomic parameters of bread wheat following different precursor crops gena 1997 and bona, 1996 and 1998, Sinana.

	Parameters					
Source of variation	**Grain yield (kg/ha)**	**Kernels m^{-2} (no.)**	**Spikes m^{-2} (no.)**	**Grains/ spike (no.)**	**Harvest index (%)**	**Yield/spike (g)**
	Bona (meher) 1996					
Precursor crops sum square	ns	*	*	ns	ns	ns
Pulses vs. cereals & linseed	ns	*	*	ns	ns	ns
Others	ns	ns	ns	ns	ns	ns
Fertilizer rates	ns	ns	ns	ns	ns	ns
Precursor x fertilizer	ns	*	ns	ns	ns	ns
	Gena (belg) 1997					
Precursor crops sum square	ns	ns	ns	ns	ns	ns
Pulses vs. cereals & linseed	*	**	ns	ns	ns	ns
Cereal vs. linseed	ns	ns	ns	*	ns	**
Others	ns	ns	ns	ns	ns	ns
Faba bean vs. field pea	ns	ns	**	ns	ns	ns
Fertilizer rates	ns	ns	ns	ns	ns	ns
Precursor x fertilizer	ns	ns	ns	ns	ns	ns
	Bona (meher) 1998					
Precursor crops sum square	ns	ns	ns	ns	ns	ns
Pulses vs. cereals & linseed	***	***	ns	*	ns	*
Cereal vs. linseed	ns	**	ns	ns	ns	ns
Wheat vs. barley	ns	*	ns	ns	ns	ns
Others	ns	ns	ns	ns	ns	ns
Fertilizer rates	***	***	ns	**	*	*
Precursor x fertilizer	ns	ns	ns	ns	ns	ns

Table 4. Effect of precursor crops on grain yield and other agronomic parameters of bread wheat, gena 1997 and bona 1996 and 1998, Sinana.

Precursor crop	Grain yield (kg/ha)	Kernels m^{-2} (no.)	1000 KW (g)	Spikes m^{-2} (no.)	Kernels /spike (no.)	Harvest index (%)	Yield/ spike (g)	Plant height (cm)	Straw yield (kg/ha)
		Bona (meher) 1996							
Wheat	3265	9834	33.23	337	29.65	30.00	0.983	117.13	7875
Barley	3398	10822	31.43	308	35.36	29.50	1.110	117.40	9060
Emmer wheat	3145	9651	32.59	282	34.61	29.72	1.126	117.30	7605
Faba bean	3674	11409	32.23	315	37.5	26.08	1.280	116.17	10776
Field pea	3359	10298	32.66	297	35.32	28.05	1.151	116.67	8694
Linseed	3284	9759	33.62	304	33.33	28.19	1.250	116.57	8417
Mean	3354	10296	32.63	307	34.29	28.26	1.170	116.87	8738
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
C.V.(%)	9.24	9.67	4.21	17.8	21.98	10.52	22.19	2.64	21.54
		Gena (belg) 1997							
Wheat	4104	11583	35.43	345	23.35	31.38	0.828	110.00	9039
Barley	3990	11505	34.67	383	23.69	31.52	0.818	106.67	8736
Emmer wheat	4220	11809	35.73	354	25.66	31.81	0.917	108.50	9089
Faba bean	4386	12412	35.37	406	25.51	30.58	0.901	110.67	10019
Field pea	4337	12271	35.37	340	24.87	31.10	0.880	110.00	9687
Linseed	4341	12102	35.87	390	26.91	30.62	0.965	110.67	9969
Mean	4230	11942	35.41	370	25.00	31.17	0.885	109.42	9423
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
C.V.(%)	6.97	6.35	2.86	10.53	9.38	7.48	10.08	4.82	14.5
		Bona (meher) 1998							
Wheat	3436	9240	37.20	616	29.99	28.20	1.117	8.55	8921
Barley	3798	10239	37.17	612	31.69	31.23	1.173	92.20	8392
Emmer wheat	3388	9274	36.50	642	30.04	29.49	1.100	85.45	8040
Faba bean	4159	11431	36.50	699	36.81	29.95	1.339	91.02	9746
Field pea	4005	10820	37.10	653	33.45	29.91	1.239	90.65	9448
Linseed	3786	10104	37.63	675	29.85	29.34	1.120	93.65	9119
Mean	3762	10184	37.02	650	31.97	29.67	1.182	90.25	8944
LSD(0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
C.V.(%)	8.19	8.8	2.48	11.08	14.87	8.16	14.58	4.7	9

Table 5. Effect of fertilizer rates on grain yield and agronomic parameters of bread wheat gena 1997 and bona 1996 and 1998, Sinana.

Parameters									
$N\text{-}P_2O_5$ rates (kg/ha)	Grain yield (kg/ha)	Kernels m^{-2} (no.)	1000 KW (g)	Spikes m^{-2} (no.)	Kernels /spike (no.)	Harvest index (%)	Yield /spike (g)	Plant height (cm)	Straw yield (kg/ha)
			Bona (meher) 1996						
9-23	3303	10175	32.50	307	34.04	29.52	1.11	115.6	7995
41-46	3405	10417	32.75	307	34.55	27.00	1.13	118.2	9480
F-value	0.9	0.53	0.31	0.0005	0.04	6.45	0.08	6.4	5.6
Prob.	ns	ns	ns	ns	ns	0.03	ns	0.03	0.04
			Gena (belg) 1997						
9-23	4177	11812	35.40	363	25.24	31.55	0.89	108.9	9128
41-46	4282	12082	35.42	377	24.76	30.80	0.88	109.9	9718
F-value	1.13	1.14	0.0097	1.19	0.38	0.96	0.33	0.36	1.7
Prob.	0.3	0.3	ns	0.3	ns	ns	ns	ns	0.22
			Bona (meher) 1998						
9-23	3483	9381	37.17	602	29.87	29.36	1.11	86.96	8374
41-46	4041	10988	36.90	697	34.07	30.01	1.25	93.50	9514
F-value	29.6	29	2.5	15.7	7.03	0.66	6.13	21.7	18.5
Prob.	0.0002	0.0002	0.09	0.002	0.02	ns	0.03	0.0006	0.001

Table 6. Regression and correlation coefficients of agronomic parameters of bread wheat grown following different crops gena 1997 and bona 1996 and 1998, Sinana.

Parameters	Model	R^2	P	N
Straw yield (kg/ha)	-22231 + 296.3 * plant height	0.48	0.008	12
Yield/spike (g)	-1.216 + 0.035 * 1000 KW + 0.035 * kernels/spike	0.999	0.000	12
Kernels/m^2 (no.)	-6933 + 23.5 * productive tillers +297.8 * kernels/spike	0.977	0.000	12
Grain yield (kg/ha)	-3746 + 107 *1000 KW + 0.35 * kernels/m^2	0.998	0.000	12

IMPACT OF CROPPING SEQUENCE AND FERTILIZER APPLICATION ON KEY SOIL PARAMETERS AFTER THREE YEARS OF A CROP ROTATION TRIAL

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ABSTRACT

A rotation trial was established at Njoro, Kenya, in 1992 to assess the impact of 16 cropping sequences and four fertilizer levels on crop productivity and soil parameters in a wheat-based cropping system. Soybean (*Glycine max*), rapeseed (*Brassica napus*), potato (*Solanum tuberosum*) and maize (*Zea mays*) were grown in rotation with wheat (*Triticum aestivum*); the control treatment consisted of continuous wheat. Post-harvest soil samples were taken from three depths in 1994 and analyzed for soil organic matter (SOM), pH, NO_3-N, and P. SOM was not influenced by cropping sequence. Applied N with or without P significantly increased SOM, while applied P with or without N significantly decreased SOM. Measurable P was not influenced by cropping sequence or by applied N, but was significantly increased by applied P. Soil NO_3-N was highly influenced by cropping sequence at all sampled depths, and by applied N at the top two depths. Crop rotations including potato exhibited higher levels of soil NO_3-N relative to continuous wheat. The other crop rotations did not apparently influence soil NO_3-N level. Soil pH was neither influenced by cropping sequence or by applied N or P.

INTRODUCTION

The predominant cropping systems in the wheat growing areas of Kenya invariably include wheat as the main crop, either grown continuously or rotated with other cereals or grass leys. Such cropping systems may lead to diminished soil fertility (Hargrove *et al.*, 1983); other problems associated with continuous cereal production include the buildup of specific diseases, weeds and insect pests (Heenan *et al.*, 1990). These problems will in the long run translate into reduced yields and hence lower returns for the farmer. Also, the need to maintain soil organic matter (SOM) in any cropping system cannot be over-emphasized due to the myriad functions that SOM performs in enhancing the availability of nutrients to crops (Palm *et al.*, 1997). For sustainable crop production, rotation with legumes and other non-cereal crops has been identified as an effective method of maintaining soil fertility with minimal use of expensive mineral fertilizers (Asefa *et al.*, 1992). Furthermore, an optimal rotation system can break the disease, weed and insect pest cycles that are be associated with wheat monoculture, or other cropping systems dominated by cereals.

To date, there has been little information generated regarding the long-term effects of crop rotation and of continuous annual fertilizer application on key soil parameters in the wheat based cropping systems of Kenya. The objective of the current trial was to determine the effects of

specific cropping sequences and constant fertilizer application rates on the relevant soil parameters affecting crop yields.

MATERIALS AND METHODS

A long-term crop rotation trial was established at the NPBRC (KARI), Njoro, Kenya in 1992 to assess the impact of sixteen specific cropping sequences and four constant nutrient application rates as main plots and sub-plots, respectively, on total crop productivity and the key soil parameters in a wheat-based cropping system. The experimental site is at an altitude of 2160 m a.s.l. on a soil classified as a well-drained mollic Andosol (FAO classification). The site receives an average annual precipitation of 930 mm with a mean monthly temperature of 14.5°C during the wheat cropping season.

The experiment was laid out as an RCBD with split-plot assignment of treatments; cropping sequences were assigned to main plots (i.e., 6 x 18 m) and nutrient rates to sub-plots (i.e., 6 x 4.5 m). Design considerations put forward by Cady (1991) were taken into account in the design of the crop rotations: the sixteen cropping sequences used (see below) consisted of five unique three-course rotations of wheat with soybean, rapeseed, potato and maize (i.e., balanced with years) and a continuous wheat treatment. Four nutrient rates (i.e., $N:P_2O_5$ at 0:0, 0:46, 60:0, 60:46 kg ha^{-1}) were examined as constant annual applications within each cropping sequence. Urea and TSP (triple superphosphate) were the sources of N and P_2O_5, respectively.

Treatment	Cropping sequence		
	1992	1993	1994
1	RP	W	W
2	W	W	RP
3	W	RP	W
4	SOY	W	W
5	W	W	SOY
6	W	SOY	W
7	POT	W	W
8	W	W	POT
9	W	POT	W
10	MAZ	W	W
11	W	W	MAZ
12	W	MAZ	W
13	MAZ	POT	W
14	POT	W	MAZ
15	W	MAZ	POT
16	W	W	W

RP = Rapeseed; SOY = Soybean; POT = potato; MAZ = Maize; W = Wheat.

Subsequent to harvest of all crops sown in the 1994 season, soil samples were taken from the 0-15, 15-30, and 30-60 cm depths of all sub-plots and analyzed for pH (in water), NO_3 (Bremner, 1965), and soil P (Mehlich, 1958). Soil organic matter (Walkley and Black, 1947) was determined from the 0-5 cm depth. Data on these soil parameters form the basis of this paper.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) of the main effects of crop rotation, N and P on key soil parameters at various depths (Table 1) revealed that SOM was not influenced by cropping sequence: all cropping sequences were equivalent to continuous wheat in terms of the level of SOM in the top 5 cm of the soil. The application of fertilizer N, however, significantly ($P<0.001$) increased SOM. This could be anticipated from the increased biomass production reported in the N-fertilized plots (Nassiuma *et al.*, 1996), and the subsequent breakdown of crop residues to form SOM. Application of P significantly ($P<0.05$) decreased SOM. There is no apparent explanation for this observation because plots receiving P also produced more residues and hence would be expected to result in elevated levels of SOM. No interaction effects were observed among the various factors determining SOM.

Extractable P was neither influenced by cropping sequence nor by applied N (Table 1). This is in contrast to the finding by Amanuel *et al.* (1994) where measured soil P levels were elevated following a crop of faba bean (*Vicia faba*). However, applied fertilizer P significantly ($P<0.001$) increased extractable P in the top 15 cm, but not in the lower soil depths. This residual effect demonstrated the expected immobility of applied P.

Measurable NO_3-N was highly influenced by both cropping sequence and applied fertilizer N (Table 1). Cropping sequence influenced NO_3-N at all sampled depths, while applied N influenced NO_3-N in the top two depths.

The ANOVA of the effects of the same experimental factors combined across soil depths (Table 2) indicates that cropping sequence and applied N had highly significant ($P<0.001$) effects on measurable NO_3-N. Depth also significantly ($P<0.001$) influenced measurable NO_3-N, and there were significant interactions between nitrogen and depth ($P<0.001$) and also between cropping sequence and depth ($P<0.05$). Other factors and interactions were not significant in influencing measurable NO_3-N.

Extractable P was significantly ($P<0.001$) increased by applied fertilizer P when analyzed across all depths (Table 2). Soil depth and the interaction between applied P and depth both exhibited highly significant ($P<0.001$) effects on extractable soil P. There was also a relatively weak interaction between cropping sequence and depth ($P<0.05$). All other experimental factors and interactions had no significant ($P>0.05$) effect on extractable P.

Regarding soil pH (Table 2), only the effect of soil depth and the interaction between rotation and depth were significant ($P<0.001$).

Cropping sequence means for soil OM, P, NO_3-N and pH (i.e., the latter three parameters averaged across the three sampled depths) are shown in Table 3. There were no cropping sequence effects on SOM, soil P, or soil pH. This is also in contrast to the findings of Amanuel *et al.* (1994) who reported that continuous wheat plots exhibited elevated pH values after eight years of a crop rotation trial.

However, in the current study, cropping sequence significantly ($P<0.001$) influenced soil NO_3-N analyzed across the three soil depths sampled (Table 3). When ranked in order, it was apparent that the highest five NO_3-N levels originated from plots that had produced a potato crop during at least one year in the three year period. Plots with potato during 1994 (i.e., treatments 8 and 15)

exhibited higher levels of NO_3-N than those that had potato one or two years prior to sampling (i.e., treatments 7, 9, 13 and 14). This indicates that the effect of potato on soil NO_3-N was greatest immediately post-harvest and declined over the three years of the experimental period. Overall, treatments including potato had higher levels of NO_3-N relative to continuous wheat. Interestingly, complex sequences (i.e., treatments 13 to 15) that had potato and maize in rotation with wheat exhibited higher levels of NO_3-N compared to other sequences (i.e., treatments 10 to 12) that had maize in rotation with wheat, suggesting a beneficial effect of potato in the rotation system.

It is not apparent why potato — which is a high consumer of nutrients — would be such a good break crop for wheat. It could, however, be expected that potato residues, being relatively succulent, would decompose faster than other crop residues and thus would initially result in higher soil NO_3 levels relative to the other crops. The microbially-mediated decomposition process results in the simultaneous mineralization of soil organic-N and the immobilization of inorganic-N by the microbial population. Net mineralization occurs when the microbial population releases more N during decomposition than it can assimilate, while net immobilization occurs when the microorganisms assimilate more N than is being released from the decomposing OM. These processes are affected by the C:N ratio of the decomposing material — mineralization occurs during the decomposition of material with a narrow C:N ratio and vice versa for immobilization (Jenkinson, 1971). Considering the N content of crop residues, soybean with 2.2% N would be expected to result in net mineralization on decomposition — relative to a suggested threshold level of 1.5% N at which immobilization and mineralization are in balance (Smith *et al.*, 1982). Wheat and maize straw with 0.7 and 1.1% N content, respectively, would be expected to immobilize N during decomposition. The N content for rapeseed and potato crop residues were not found in literature.

It has also been reported that soil disturbance — as occurred during potato harvest — enhances the decomposition of crop residues due to increased exposure of the residues to microbial attack (Wall *et al.*, 1994). These authors indicated that soil disturbance tends to aerate the soil, leading to rapid oxidation of OM. This would be particularly relevant when disturbed soil is wetted by rain showers soon after harvesting the potato crop. Mean levels of NO_3-N after rotation with potato, soybean, maize and rapeseed follow in that order of magnitude. The fact that soybean did not have a bigger effect on soil NO_3-N may have been due to poor N fixation. Poor nodulation of soybean was observed during the trial period because the seed had either been improperly inoculated or the rhizobial inoculant applied had not been effective.

Rapeseed was a poor break crop, resulting in a mean soil NO_3 level even lower than that of continuous wheat plots. Maize was apparently a better break crop than rapeseed although this had not been anticipated — due to the long time required for maize stover to decompose relative to residues from the other crop species. Among the treatments including rapeseed, soil NO_3 level was lowest where rapeseed had been produced in 1994. The same trend was apparent for treatments based on maize as the break crop. This suggests that these crops were big consumers of N, and that soil NO_3 gradually recovered during the second and third succeeding years — when the plots were sown to wheat. This therefore indicates that these crops were not beneficial to the soil with respect to soil N supply. In contrast, the trend for soybean and potato was exactly the opposite. Soil NO_3 levels were highest immediately following these crops, but declined over time during the period of wheat production. This indicates a beneficial effect of these two crops on soil N levels vis-a-vis continuous wheat production.

Cropping sequence by depth interaction means for soil NO_3 level reveal a significant general decline in NO_3 levels down the soil profile for all rotation sequences (Table 4). However, the decline from the first to second soil depths was more pronounced on plots with potato in the second phase (i.e., 7.8 ppm for treatment 9) and lowest on plots with soybean in the third phase (i.e., 2.1 ppm for treatment 5). Also, the differential effects of cropping sequences were more apparent in the observed change in soil NO_3 level from the second to the third depth; the decline in soil NO_3 level across this interval was only significant for treatments 5, 8, 15 and 16.

In general, extractable P declined down the soil profile — an expected phenomenon due to P immobility (Table 5). However, a significant differential effect resulted from the relatively large decline in soil P level on plots that had potato in the second or third phase (i.e., treatments 8 and 9) vs. the relatively low decline on plots that had rapeseed in the third phase (i.e., treatment 2). Also, the differential effects of cropping sequences were apparent in the observed change in P level from the second to the third soil depth; the decline in soil P level across this interval was only significant for treatments 6, 8, 9 and 14.

There was a general increase in pH down the soil profile (Table 6) that could be attributed to the use of acidifying fertilizers on this site and, thus, a reduction in the pH of the surface soil layer. Tanner *et al.* (1993) also reported that fertilizer N reduced pH in the surface soil layer after only one year of application in on-farm fertilizer trials. The significant interaction between rotation and depth may have been due to different magnitudes of decline for the various cropping sequences, but no discernible trend was apparent in the data.

Annual application of 60 kg N ha^{-1} increased soil NO_3 levels at all three soil depths relative to the nil rate (Table 7). This constant differential throughout the soil profile can be explained by the high mobility of N in soil. In contrast, annual application of 46 kg P_2O_5 ha^{-1} only increased extractable P in the upper (i.e., 0-15 cm) soil depth; this confinement of P to the upper layer is entirely due to the relative immobility of P in the soil.

The results of the current study demonstrated differential effects of cropping sequences on key soil parameters. Cropping sequence exhibited the most dramatic effect on soil N. The selection of crops to grow in rotation with wheat can have a significant effect on soil parameters. Some of the observations from the current trial could not be satisfactorily explained, and more work may be required to explain these results.

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Table 1. Results of the ANOVA of the effects of rotation (R), nitrogen (N), and phosphorous (P) on key soil chemical parameters measured post-harvest 1994 at several depth intervals (cm) at Njoro, Kenya.

	Parameters[a]									
	OM	P			NO_3			pH		
Factor	0-5	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
R	NS	NS	NS	NS	***	**	**	NS	NS	NS
N	***	NS	NS	NS	***	*	NS	NS	NS	NS
R x N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
P	*	***	NS	NS	NS	NS	NS	NS	NS	NS
R x P	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x P	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
R x N x P	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.(%)	10.8	10.3	16.5	15.1	7.1	12.6	14.2	1.7	1.9	1.9
Mean	3.62	29.0	22.2	19.8	30.1	25.6	24.3	6.17	6.25	6.35

*, **, ***: Significant at the 5, 1 and 0.1% level, respectively.
NS: Not significant.
[a]OM = Soil organic matter (%); P = Soil P (ppm); NO_3 = Soil NO_3 (ppm); pH = Soil pH.

Table 2. Results of the ANOVA of the effects of rotation (R), nitrogen (N), and phosphorous (P) combined across soil depths (D) on key soil chemical parameters measured post-harvest 1994 at Njoro, Kenya.

		NO_3		P		pH	
	d.f.	F	Prob.	F	Prob.	F	Prob.
Rotation (R)	15	4.52	***	0.41	NS	0.56	NS
Nitrogen (N)	1	49.01	***	0.05	NS	0.04	NS
R x N	15	0.85	NS	1.73	NS	1.04	NS
Phosphorous (P)	1	0.01	NS	25.21	***	0.04	NS
R x P	15	0.62	NS	0.95	NS	1.11	NS
N x P	1	0.00	NS	0.27	NS	2.17	NS
R x N x P	15	0.56	NS	0.81	NS	1.62	NS
Depth (D)	2	264.1	***	239.60	***	176.38	***
R x D	30	1.57	*	1.67	*	1.80	***
N x D	2	36.60	***	0.33	NS	0.25	NS
R x N x D	30	1.12	NS	0.33	NS	1.03	NS
P x D	2	0.03	NS	17.03	***	0.15	NS
R x P x D	30	0.92	NS	0.67	NS	0.78	NS
N x P x D	2	3.77	NS	0.04	NS	1.31	NS
R x N x P x D	30	1.00	NS	0.52	NS	0.75	NS
Mean		26.7		23.64		6.3	
C.V.(%)		9.82		18.07		1.45	

*, ***: Significant at the 5 and 0.1% level, respectively.
NS: Not significant.
[a] NO_3 = Soil NO_3 (ppm); P = Soil P (ppm); pH = Soil pH.

Table 3. Soil organic matter (OM), P, NO_3 and pH as influenced by cropping sequence measured post-harvest 1994 at Njoro, Kenya.

Treatment	Crop rotation			Parameter			
	1992	1993	1994	OM (%)	P (ppm)	NO_3 (ppm)	pH
1	RP	W	W	3.86	23.3	25.9 defg	6.2
2	W	W	RP	3.46	23.9	23.0 g	6.2
3	W	RP	W	3.37	24.2	24.2 fg	6.3
4	SOY	W	W	3.88	23.4	25.2 defg	6.2
5	W	W	SOY	3.92	21.8	27.0 cdef	6.2
6	W	SOY	W	3.91	25.6	26.5 cdef	6.4
7	POT	W	W	3.56	26.7	27.7 bcd	6.4
8	W	W	POT	3.12	26.3	31.6 a	6.3
9	W	POT	W	3.18	23.4	26.6 cdef	6.3
10	MAZ	W	W	3.23	21.8	26.2 cdef	6.3
11	W	W	MAZ	4.08	21.7	24.4 fg	6.2
12	W	MAZ	W	3.55	22.8	26.7 cdef	6.3
13	MAZ	POT	W	3.71	22.7	29.3 abc	6.2
14	POT	W	MAZ	3.57	22.3	27.6 bcde	6.3
15	W	MAZ	POT	3.83	25.0	30.3 ab	6.2
16	W	W	W	3.74	23.4	24.5 efg	6.3
Grand mean				3.62	23.6	26.7	6.3
LSD(0.05)				NS	NS	3.12	NS
C.V.(%)				10.8	18.0	9.8	1.45

Within a column, values followed by the same letter(s) are not significantly different at the 5% level of the LSD test.
RP = Rapeseed; SOY = Soybean; POT = potato; MAZ = Maize; W = Wheat.

Table 4. Soil NO_3 (ppm) as affected by rotation and depth of sampling.

Depth (cm)	Rotation sequence																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean
0-15	29.1a	26.7a	27.9a	28.7a	29.2a	29.8a	31.0a	36.2a	32.4a	29.3a	27.0a	29.4a	32.8a	30.9a	34.0a	27.7a	30.1A
15-30	24.6b	21.7b	22.8b	24.0b	27.1b	25.7b	25.4b	31.3b	24.6b	24.9b	23.5b	25.8b	28.2b	26.1b	29.6b	24.4b	25.6B
30-60	24.1b	20.5b	21.8b	22.9b	24.7c	24.1b	26.7b	27.2c	22.8b	24.4b	22.7b	25.0b	26.9b	26.0b	27.4c	21.4c	24.3C
LSD(0.05)	2.11																0.53

Within each column, values followed by the same letter are not significantly different at the 5% level of the LSD test.

Table 5. Soil P (ppm) as affected by rotation and depth of sampling.

Depth (cm)	Rotation sequence																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean
0-15	28.0a	27.3a	28.0a	27.8a	29.0a	31.2a	31.7a	32.8a	30.7a	26.8a	26.9a	25.7a	28.7a	29.8a	31.0a	28.3a	29.0A
15-30	21.4b	23.2b	23.3b	21.3b	19.8b	25.1b	25.1b	26.9b	21.8b	20.7b	19.3b	21.3b	20.9b	21.1b	22.6b	21.8b	22.2B
30-60	20.4b	21.3b	21.3b	21.3b	16.6b	20.7c	23.3b	19.1c	17.7c	18.0b	18.8b	21.5b	18.5b	16.0c	21.8b	20.3b	19.8C
LSD(0.05)	3.43																0.859

Within each column, values followed by the same letter are not significantly different at the 5% level of the LSD test.

Table 6. Soil pH as affected by rotation and depth of sampling.

Depth (cm)	Rotation sequence																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean
0-15	6.06c	6.11c	6.17c	6.18b	6.18b	6.26c	6.29c	6.26b	6.23c	6.18b	6.08c	6.19b	6.07c	6.24a	6.08b	6.19b	6.17C
15-30	6.13b	6.24b	6.30b	6.23ab	6.13b	6.38b	6.38b	6.28b	6.32b	6.24b	6.18b	6.29a	6.19b	6.25a	6.12b	6.25b	6.25B
30-60	6.29a	6.34a	6.40a	6.27a	6.28a	6.49a	6.47a	6.36a	6.45a	6.33a	6.30a	6.36a	6.31a	6.29a	6.25a	6.34a	6.35A
LSD(0.05)	0.072																0.018

Within each column, values followed by the same letter are not significantly different at the 5% level of the LSD test.

Table 7. Nitrogen rate by depth interaction effects on soil NO_3.

N rate (kg ha^{-1})	Depth (cm)	Soil NO_3 (ppm)
0	0-15	27.8 b
	15-30	25.1 d
	30-60	23.9 e
60	0-15	32.6 a
	15-30	26.1 c
	30-60	24.7 d
LSD(0.05)		0.75
Mean		26.7

Values followed by the same letter are not significantly different at the 5% level of the LSD test.

Table 8. Phosphorous rate by depth interaction effects on soil P.

P_2O_5 rate (kg ha^{-1})	Depth (cm)	Soil P (ppm)
0	0-15	26.7 b
	15-30	22.2 c
	30-60	19.7 d
46	0-15	31.2 a
	15-30	22.2 c
	30-60	19.8 d
LSD(0.05)		1.21
Mean		23.6

Values followed by the same letter are not significantly different at the 5% level of the LSD test.

THE INTRODUCTION OF DISEASE AND PEST RESISTANT WHEAT CULTIVARS TO SMALL-SCALE FARMING SYSTEMS IN THE HIGHLANDS OF LESOTHO

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ABSTRACT

Summer wheat is one of the major crops planted by farmers in the highlands of Lesotho. The crop is used by subsistence farmers for food, roofing material, fuel and seed. Currently, farmers are using "farmer varieties" dating back to the early 1960s and 80s. No adoption of new cultivars with modern traits such as Russian wheat aphid or yellow rust resistance has taken place in the area. A partnership was forged between the ARC-Small Grain Institute and GROW, a development agency operating in the Mokhotlong Valley, to introduce and evaluate new varieties utilizing nurseries of the agency's Seeds of Wellbeing project. New cultivars look promising in terms of yield increase, but they have not yet been sufficiently evaluated with regards to stability and adaptation to the environment. Suitability of new cultivars to farmers' needs will be determined through farmer participation in the trials and by testing selected cultivars in farmers' own field plots. It is foreseen that research capacity in the area and the linkages between research, the development agency and farmers in the field, will be strengthened as a result of this partnership.

INTRODUCTION

Summer wheat is one of the major crops planted by farmers in the Highlands of Lesotho. The crop provides food, roofing material, fuel and seed to subsistence farming households (Collinson, 1989; Rosenblum, Ts'iu and Moletsane, 1999) who grow the crop at elevations of 2100-2300 m. The crop is typically established with carryover seed from the previous season soon after the onset of the spring rains. According to Rosenblum *et al.* (1999), varieties used by farmers are not pure and can be divided into six different types or "farmer varieties". Though mixing of varieties may be purely accidental, genetic variation within the local wheat populations could contribute to sustainability of production by reducing risks of specific threats to overall harvest (Worede and Mekbib, 1993 as quoted by Rosenblum *et al.* (1999)). The same authors point out that modern high yielding genotypes rarely outperform farmers' traditional varieties and they quote Majoro and Holland (1986) who stated that this had been the case in Mokhotlong as modern varieties released there in the past had not significantly increased yields.

According to a survey performed by Rosenblum *et al.* (1999), farmers described the three wheat varieties most commonly used as *Bolane*, *Mants' a Tlala* and *Mohohlotsane*. *Bolane* is a tall variety that was included in cultivar trials in Maseru during the sixties (Weinmann, 1966). As a variety it did not show much potential for yield and was consistently outperformed by other cultivars during that time. It has a low tillering capacity and prominent

awns with long spikes. The variety is used for baking bread and the tall straw is ideally suited for roofing.

The variety named *Mants' a Tlala* was released as Tugela in South Africa in 1985 and promoted in Lesotho afterwards. The variety has an intermediate canopy with high tillering capacity. It has brown seeds and is considered to have "heavy flour" for baking bread. This observation by farmers is consistent with the well-known fact that the cultivar Tugela has a longer than average mixing time. Although not verified on-site, the cultivar should also have genetic resistance to current strains of yellow (stripe) rust (*Puccinia striiformis* Westend. F. sp. *tritici* Eriks.).

Mohohlotsane is an awnless variety of medium canopy height and unknown origin. It has very dense spikes and the grain is easily threshed from the spikelets, making it very prone to bird damage. The grain is sweet and used with peas to make a local dish. It is also milled into rough textured flour for baking bread.

Farmers also plant a durum variety Telo Nts'o (*Triticum durum*) on a small scale. This variety has distinctive black spikes with prominent awns. The tall straw is very suitable for thatching, but farmers found the seed hard to mill in the past. Acceptance of the variety was low because of this. However, a survey to characterize and recover traditional varieties has sparked renewed interest in Telo Nts'o, especially as one community now has access to a mechanized mill.

None of the "farmer varieties" were tested for Russian wheat aphid (RWA) resistance, but visual observations indicated that none of them has resistance to the aphid. Due to the high rainfall and low temperature regime in the Mokhotlong Valley, Russian wheat aphid (*Diuraphis noxia*) is a sporadic pest in the area. It can however be devastating if high infestation levels occur during drought periods at sensitive growth stages. Heavy infestations of other aphid species such as the Oat aphid (*Rhopalosiphum padi*) are frequently observed. None of the "farmer varieties" except *Mants' a Tlala* (Tugela) are considered to be resistant against current strains of yellow rust, which were first reported in Southern Africa in 1997 (Boshoff, Van Niekerk and Pretorius, 1999).

An improved version of Tugela with resistance to RWA was officially released by the ARC-Small Grain Institute in 1994 with the name Tugela-DN (TUG*4/GANDUM I FASAI). This cultivar was provided to Lesotho under the name Puseletso during 1992 (Moremoholo and Purchase, 1999). It is considered to have excellent agronomic attributes such as high yields and resistance to both acid soils and yellow rust. Having more than 90% of the original cultivars genetic makeup, it could easily replace its predecessor *Mants' a Tlala* (Tugela). Unfortunately, it was still unknown to farmers in the Lesotho Highlands in 1999.

The conservation and further improvement of locally adapted, useful and reliable genetic resources should not be compromised by introducing modern high yielding cultivars into environments to which they are not suited. Such interventions could have disastrous consequences for the small-scale resource poor farmers that rely on the crop as the main source of food. Pest and disease resistant cultivars do however offer farmers protection against major crop losses caused by newly introduced pests and diseases, previously unknown in the area such as yellow rust. All new technological interventions should be economically viable, environmentally sound, socially acceptable and politically supportable

(Reeves, 1999). For this reason, new cultivars should be introduced with caution without being prescriptive, and with full participation of farmers in the process.

MATERIALS AND METHODS

The need to check the usefulness of cultivars with resistance to Russian Wheat Aphid and yellow rust in the Mokhotlong Valley lead to a partnership between the ARC-Small Grain Institute and GROW a locally based Non-Governmental Organization. For this purpose, the development approach and nurseries of GROW were used as part of their "Seeds of Well being Project (SOW).

As a first step, the new cultivars were planted in a nursery situated at Makoabateng within the Mokhotlong Valley with full participation of farmers. Here farmers work with, and get to know the material. After one or two research cycles, participating farmers can select cultivars they wish to include in their own on–farm experimental plots. During this stage, not only the agronomic traits such as yield and stability are evaluated, but also other criteria such as the usefulness of the straw for roofing and fuel as well as cooking and baking characteristics.

During the 1999/2000 season, farmers' wheat varieties and new cultivars were included in unreplicated plots in the Makoabateng nursery (Mokhotlong Valley). The altitude of the trial site is 2440 m. To simulate farmers' conditions, no external inputs such as fertilizers, pesticides or seed treatments were used. Two planting dates namely 8 October 1999 (early planting) and 23 November 1999 (late planting) were used. The later planting took place later than usual due to drought conditions prevalent at that time. The "farmers varieties" *Bolane*, *Mants' a Tlala* and Telo Nts'o were retained and the following new cultivars were included in the nursery:

- **Puseletso** - a RWA Resistant version of *Mants' a Tlala.* Also has resistance against yellow rust and acid soils.
- **SST 333** - a fast growing RWA resistant cultivar similar to SST 124, suitable for late planting dates.
- **Elands** – a newly released cultivar with high yield potential and good RWA resistance. It was included to see if it's genetic potential could be realized under the environmental conditions in the area.

RESULTS

Good yields were obtained with the early planting of the crop (Table 1). As could be expected, 'SST 333' a cultivar with a short growth period, was the only cultivar that performed well when planted late in the season. Puseletso yielded well at the earlier planting date; Tugela and Puseletso yielded similarly at the later planting date. The data indicate that substantial improvement with regards to yield can be made with new varieties like Elands and SST 333 due to higher yield potential of such cultivars. Telo Nts'o the durum variety with tall straw, did not reach the yield level of the wheat cultivars, but it must be kept in mind that farmers plant it for dual purposes; as a source of food and for roofing.

DISCUSSION AND CONCLUSION

Inclusion of new cultivars in the Makoabateng nursery has indicated that there is potential for substantial wheat yield increase in the Mokhotlong Valley. The adaptability and stability of

these new cultivars to the particular environment could not be concluded due to insufficient data. Furthermore, farmers have not yet had the opportunity to evaluate the suitability of the new cultivars regarding purposes for which the crop is planted. It is therefore recommended that the evaluation of new useful cultivars be continued following this participatory on-farm approach. This can be achieved by strengthening both farmers' research capacities and the linkages between them, research agencies, and development organizations. Such an approach will aid the conservation of valuable locally adapted genetic resources and help farmers improve their position by 1) gaining access to genetic resources that provide solutions for new threats and 2) expand their capacity to evaluate new cultivars and farming techniques.

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Questions and Answers:

Colin Wellings: (1) I presume Tugela and Tugela-DN are closely related; (2) Have these cultivars been affected by the Hugenoot pathotype of yellow rust? (3) **Comment:** It will be important to monitor rust pathotypes in these highland summer cereal cropping locations. Perhaps trap nurseries could be considered for this.

Answer: (1) Tugela and Tugela-DN are near isogenic lines differing only in RWA resistance; (2) The Tugela types are as yet not infected by the YR pathotypes present in Lesotho and RSA; (3) Due to the high altitude and weather conditions (of the site), it is an ideal location for rust traps – no fungicides are used in the area, allowing for natural epidemic development.

Ravi P. Singh: The environment of Lesotho is completely different from South Africa, so are you planning to evaluate genotypes adapted to highlands that are similar to the Lesotho environment?

Answer: Yes. Collaboration with international breeders to evaluate suitable entries is needed to improve the chances of finding successful introductions. Agreements among local stakeholders need to be reached on all interventions.

Ravi P. Singh: It will be better not to grow one of the main South African cultivars in the Lesotho highlands to avoid the evolution of a new race that can cause a problem in South Africa.

Answer: Yes, we agree. Better adapted and more suitable lines to introduce are being sought.

Table 1. Yield (t/ha) of six wheat cultivars, at two planting dates in Makoabateng, Lesotho.

Cultivar	Yield (t/ha)	
	Early planting 8 October 1999	Late planting 23 November 1999
Elands	3.93	3.50
SST 333	3.60	4.00
Puseletso	3.75	2.45
Tugela	-	2.40
Bolane	-	3.00
Telo Nts'o	-	2.60

REDUCING MECHANICAL HARVESTING LOSSES OF WHEAT UNDER LARGE-SCALE PRODUCTION IN THE GEZIRA SCHEME, SUDAN

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ABSTRACT

About 168,000 ha in the Gezira Scheme are sown annually to wheat (*Triticum aestivum* L.). Wheat production is fully mechanized, and harvesting usually occurs during March and April. About 300 combine harvesters are involved in wheat harvesting, and almost all of these machines are privately owned. The most common type is the self-propelled combine harvester equipped with a 4.5 m wide grain header. One of the most serious problems of using combine harvesters is the high harvesting losses: an estimated 18-20% of the produced crop is lost during harvesting. This high harvest loss costs the farmer, the scheme management, and the country. The objectives of this research project were to investigate causal factors affecting wheat harvest losses in the Gezira, to quantify these losses, and to propose a plan to minimize such losses. Research was conducted at the Gezira Research Station at Wad Medani for two seasons (1991/92-1992/93) to estimate the effect of time of harvesting on wheat harvesting losses. Also, a project to reduce wheat harvest losses was started in 1993/94, involving four approaches: the first approach targeted farmers and involved extension, educational and media activities; the second approach targeted combine operators; the third approach involved regulatory activities; the fourth approach included field surveys to estimate actual harvest losses and to detect of losses sources. The project ideas and efforts were highly accepted by the Gezira Scheme Management and the farmers, and adoption rates were very high. Results of the technical surveys showed excellent progress in reducing wheat harvest losses. Before the project, losses were estimated to be about 20%. Survey results showed the majority of these losses were due to machinery operational factors and management of the combine harvesters. The total decrease in harvesting losses in the first three seasons was about 13.2% equal to about 96,100 t of wheat. The value of the amount of wheat saved could be estimated to be about 38.4 billion Sudanese pounds or about US$25.6 million.

INTRODUCTION

The Gezira Scheme is one of the largest agricultural projects in the world under one management. With a total area of about 800 thousand hectares, this scheme is divided into 18 administrative groups. The scheme is located in central Sudan between the Blue Nile and the White Nile. The irrigation systems cover all the cultivated area in a hierarchical manner. Water is delivered from Sennar Dam on the Blue Nile to main canals, major canals, minor canals and ends in field ditches. Gezira Scheme is divided administratively into 18 groups and 112 blocks. The scheme follows a five-course rotation. There are about 114 thousand tenants each with a holding

ranging from 6.3 to 8.4 hectares.

Wheat is one of the crop rotation crops. It is preceded by cotton and followed by groundnut and sorghum. About 168 thousand hectares are cultivated annually with wheat. Wheat production is fully mechanized (Dawlbeit, 1996). Disc harrows and ridgers are used for seedbed preparation while seed drills and wide level disc harrows equipped with seeder boxes are used for seeding. Land preparation starts usually during the rainy season in September while seeding is during November. Private service companies and individuals execute the mechanized operations of seedbed preparation and seeding. There are about three large service companies, about ten medium companies and a large number of individually owned machines. Wheat yields are low with a mean of 1.26 t/ha (Faki and Ismail, 1994).

Harvesting is usually during March and April. About 300 combine harvesters are involved in wheat harvesting. Almost all of these machines are privately owned. The most common type is the self-propelled combine harvester equipped with 4.5m wide grain header.

One of the most serious problems of using combine harvesters is high harvesting losses. It is estimated that about 18-20% of the produced crop is lost during harvesting.

Previous Research

A study was conducted at Gezira Research Station at Wad Medani for two seasons (1991/92-1992/93) to estimate the effect of time of harvesting on wheat harvesting losses (Dawelbeit, 1996). Results, as depicted in Table 1, showed that the average total losses amounted to 2.6% in the first season and 2.3% in the second season. Results also showed that delayed harvesting could result in very high losses since the rain showers start as early as May. The table also shows that in 1992/93 season the last harvest date (May 29) which occurred after a rain shower resulted in very high grain losses.

Wheat Harvesting System in Gezira

Due to the importance of wheat harvesting, a special system was developed to manage wheat harvesting in the Gezira Scheme. A high committee for wheat harvesting at the headquarters assisted by committees on the group level is responsible for management of harvesting. This committee sets wheat harvesting regulations and prices, contracts combines, secures inputs, follows up harvesting operations, delivers wheat to flour mills and collects loans and taxes from the tenants. The committee usually starts its activities in January and ends its activities in June of every year.

All the area is harvested by harvesting contractors. For those contractors, wheat harvesting is a special season. A combine harvester usually works about 18 hours per day in two shifts. Every shift has six laborers. These include a driver, an assistant in addition to four laborers responsible for sack stitching and handling: all combine harvesters in the Sudan are equipped with a special handling system that uses jute sacks rather than bulk handling. Those laborers are temporary employed for the harvesting period only. They are paid by the area they harvest. Most of the combine operators are not trained and have a very low standard of education.

Usually, at mid wheat production season (December), a survey is made to estimate the number of available harvesting machines in the area. The number of combine harvesters that is required to

harvest the area in a period of one month is estimated to be about 300. Normally there is a shortage and great efforts are usually made to bring combine harvesters from other agricultural production areas.

Estimation of Wheat Harvesting Losses

Total wheat harvesting losses are generally divided into pre-harvest, gathering and processing losses. Wheat yield is divided into collected yield and gross yield. The following definitions are adopted:

1. Pre-harvest losses: These are the wheat seeds and spikes, which are lost on the ground and can not be collected by the combine. The reason for this pre-harvest loss could be due to crop lodging, weather factors such as wind or rains, or could be due to damage of wheat by pests such as rodents or termites.

2. Gathering losses: These are usually wheat seeds and spikes that are missed by the combine header and were lost on the ground. The main reason for gathering losses is combine operation. Research results showed that gathering losses increased with over speeding and unskilled operators.

3. Processing losses: Processing losses are those wheat seeds which are lost in threshing and cleaning, broken seeds, unthreshed wheat heads and those lost with wheat straw. The main reason for wheat processing losses is mal-adjustment of the combine harvester.

4. Total harvesting losses: Is the sum of pre-harvest, gathering and processing losses.

5. Collected yield: Actual weight of wheat harvested.

6. Gross yield: Is the sum of collected yield and total harvesting losses.

7. Percent losses: The ratio of the specific loss to the gross yield multiplied by hundred.

Minimizing Combine Harvester Losses Project

The project for minimizing wheat harvesting losses was started in the season 1993/94. The organization involved establishing a higher committee for the project. Its responsibility is to develop the annual work plans, establish committees in the different groups and to evaluate the overall performance. Members of the committee included the senior staff of the agricultural administration of the Sudan Gezira Board in addition to the agricultural engineering research scientists at Gezira Research Station.

Before launching the project, literature was collected and two pamphlets were published. The first was entitled "How to minimize wheat harvesting losses". It was written for farmers, and included information about: when to stop irrigating the wheat crop, signs of wheat crop maturity, preparations before harvesting, what to observe while the combine is working, and what to observe when the combine finishes its work. The second pamphlet targeted combine operators. It was entitled "How to increase the efficiency of the combine harvester". It included instructions of how to maintain the combine, workshop and field adjustments of the combine harvester, patterns of combine harvesting, proper combine adjustments, critical factors of operation,

optimum speeds, the importance of combine operators in minimizing wheat harvesting losses, and advice about the use of fuel and oils.

A) Project Strategy:
The project strategy involved four approaches.
The first approach: This approach targeted the farmers and involved extension, educational and media activities. The main objective was to increase farmers' awareness of the problem of high wheat harvesting losses and to show them what to do to solve this problem.
The second approach: This approach targeted the combine operators. There are about 600 of them working in wheat harvesting. The main objective was to increase operators' awareness and to improve their skills and increase their performance efficiency.
The third approach: This approach involved regulatory activities. It proposed a system for suitability tests and checking combine performance.
The fourth approach: This included field surveys to estimate actual harvesting losses and to detect their sources. This will help in diagnosing the causes and identifying the priorities for the following season.

B) Project Activities:
Great efforts had been put into the different approaches. The Sudan Gezira Board in addition to the Farmers' Bank and the Bank Consortium that was financing wheat crop production financed the Project.

In the first approach, which involved extension, educational activities such as lectures, meetings and workshops were made at the Group level (18 Groups). The topics covered in these activities included: the wheat harvesting problem and its economic implications, technical information about minimizing the losses, farmers' responsibilities towards solving this problem. Farmer leaders and extension agents conveyed these messages at the block level. There are about 112 blocks in the Gezira Scheme. The farmers at the block level conveyed the same message, in turn, to production committees at the village level. There was also full coverage of these activities by the media. In addition to these, radio and television messages were broadcast during the harvesting period.

Training of combine operators involved meetings at five locations. In these meetings the wheat harvesting problem was discussed. Technical information and practical skill was delivered to the operators. The practical aspects included calibration and checking of the combines in addition to evaluation of harvesting losses.

The Gezira Scheme endorsed regulations regarding combine suitability tests and checking of combine harvesters was performed by the Agricultural Engineering Department of the Gezira Scheme.

The field surveys were carried out during the harvesting season. These covered all of the wheat production area. About 60 combine harvesters were covered each year. The Agricultural Engineering Research Program executed these surveys at Gezira Research Station.

RESULTS

The project ideas and efforts were highly accepted and appreciated by the Gezira Scheme Management as well as the farmers. Adoption rates were very high. This was clear from the good follow-up of harvesting operations and in the increased awareness about the importance of solving this problem. Reducing wheat harvesting losses was the main topic in farmers' meetings and gatherings. This high interest was reflected in the decreased percent losses every year.

Results of the field surveys showed excellent progress in reducing wheat harvesting losses. This decreasing trend is shown in Figure 1. Before the project, losses were estimated to be about 20%. In the first year of the project, this percent decreased to 13%. In the second year (1994/95) losses were further decreased to 9.3%. By the third year, the average loss was estimated to be about 6.8%.

The total decrease in harvesting losses over the three seasons was about 13.2%, saving an estimated 96,100 tons of wheat. The per capita consumption in Sudan is about 44 kg of wheat (Pingali, 1999). Thus, the amount saved is enough to feed about 2,200,000 person annually. The value of the collected amount of wheat has been estimated at about 38.4 billion Sudanese pounds or about US$25.6 million.

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Questions and Answers:

Amanuel Gorfu: It is reported that wheat production in the Gezira Scheme is fully mechanized, irrigated and crop rotation is also practical. Regardless of crop losses after maturity (pre- and post-harvest losses), what are the major reasons for the low yields obtained from wheat in this area?

Answer: The major reasons for the low productivity of wheat under Gezira conditions is bad crop management. Some farmers (< 5%) generally produce more than 5 t/ha using the package produced by ARC of Sudan. The rest have the problem of poor management.

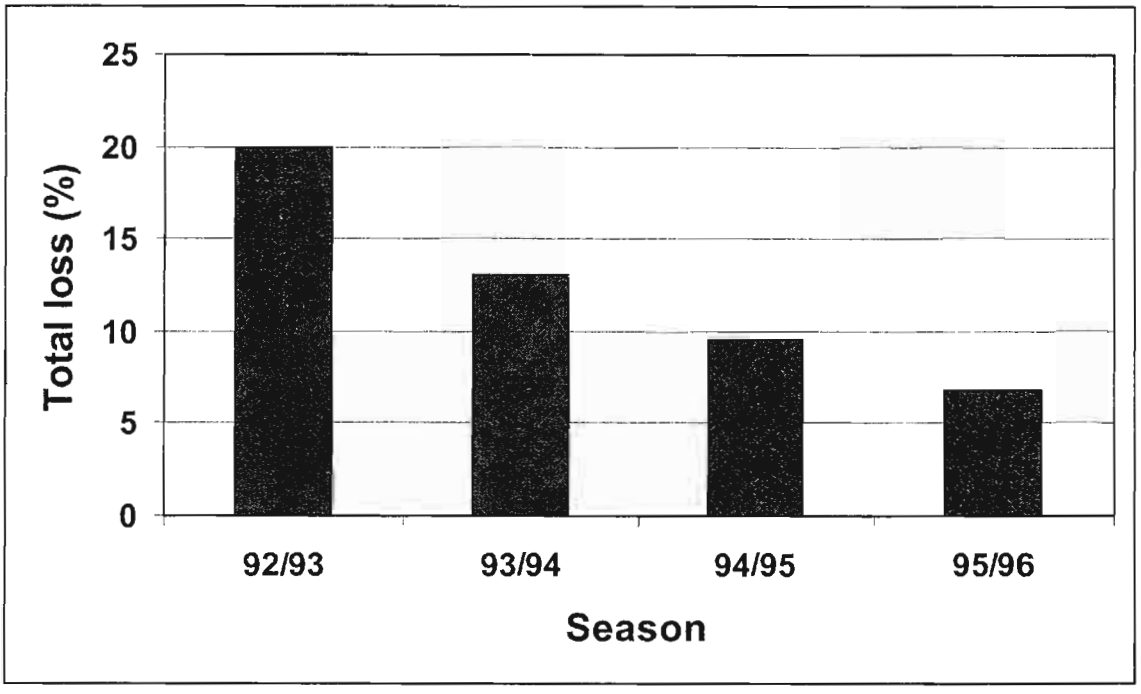

Figure 1. **Wheat harvesting losses, Gezira Scheme, seasons 1992/93-95/96.**

Table 1. **Effect of harvesting date on total grain losses in Gezira.**

1991/92		1992/93	
Date	**Total loss (%)**	**Date**	**Total loss (%)**
March 31, 1992	0.9	March 20, 1993	1.1
April 6	3.1	March 27	2.3
April 13	2.4	April 3	1.2
April 20	2.8	April 10	1.3
April 27	3.7	April 17	2.1
May 4	2.3	April 24	1.7
May 13	2.9	May 1	2.6
		May 8	2.4
		May 15	6.4
		May 29	28
Mean	2.6	Mean	2.3

EFFECTS OF CROP ROTATION, TILLAGE METHOD AND N APPLICATION ON WHEAT YIELD AT HANANG WHEAT FARMS, TANZANIA

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ABSTRACT

Crop management options which optimize tillage, residue management and herbicide practices are likely to provide more sustainable and efficient farming systems, especially in relatively marginal environments like those prevailing at the Hanang Wheat (HWC) farms. A crop rotation trial was established at the HWC from 1994/95-1999/2000 to determine whether wheat yields at the HWC farms could be improved through crop rotation with soybean and pigeon pea; rotations were compared in factorial combination with tillage practice and N application. Across four years of experimentation, rotations of wheat with soybean or wheat with pigeon pea, both under minimum tillage, resulted in the highest wheat yields, 2.82 and 2.80 t/ha, respectively. Soybean-wheat or pigeon pea-wheat rotations are recommended for improved and sustainable wheat yields at the HWC farms. However, further research is needed to determine optimal rotation frequencies. Use of N fertilizer alone is not recommended to increase wheat production at the HWC farms. However, N application of 30 kg/ha is recommended in conjunction with minimum tillage to increase wheat production at the HWC farms.

INTRODUCTION

Crop management options which optimize tillage, residue management and herbicide practices are likely to provide more sustainable and efficient farming systems especially in marginal environments like the Hanang wheat farms in northern Tanzania.

In areas where soil moisture limits plant growth, zero till (ZT) systems have been reported to produce crop yields similar to (Carter and Rennie, 1985) or higher than (Tessier *et al.*, 1990) conventional tillage (CT). However, in relatively humid environmental conditions, crop yield for ZT systems were comparable to (Carter *et al.*, 1988) or lower than (Parsons and Koehler, 1984) those obtained under CT systems. Crop response to ZT was found to be inversely proportional to the risk of compacting the soils (Rydberg, 1992). It has been found that the grain yield potential of CT practices is generally site specific (van Doren *et al.*, 1976).

Adapting crop rotation at the Hanang wheat farms can be a long-term and sustainable solution to the existing weed, soil fertility and plant disease problems which currently prevail. Alternate crops could also help in spreading the risk involved in the mono-cropping system which is the conventional practice at the HWC. Through research programs carried out at HWC farms, some crops which perform very well have already been identified that could be grown in rotation with wheat. These include: soybeans, sunflower, safflower, common beans, maize and flax. However, availability of a market for these various crops has been the major

factor limiting the HWC from adopting the various rotational crops in the wheat production system. Due to mono-cropping and other factors, wheat yield has been dropping considerably. Average wheat yield over the past five years is approximately 1.01 t/ha.

MATERIALS AND METHODS

Experimental Design and Treatments

An RCBD with split-split plot layout with 3 replications was used.

Rotational sequences (as main plots):

W = Wheat (control); Soy = Soybeans; PP = Pigeon peas

RS1	=	Soy	W	Soy	W	Soy	(for 1994/95 - 1996/97 growing seasons)
RS1	=	PP	W	PP	W	PP	(for 1997/98 - 1998/99 growing seasons)
RS2	=	W	Soy	W	Soy	W	
RS3	=	W	W	W	W	W	

Tillage methods (as sub-plots):

T1 = Conventional tillage using chisel, sweeps and sweeps (CSS) (control treatment)
T2 = Reduced tillage using chisel, followed by Roundup application then sweeps (CRS)
T3 = Zero tillage - spray with Roundup (R). This treatment was excluded in the 1997/98 and 1998/99 growing seasons

N fertilizer application levels (top dressed as urea, as sub-sub-plots):

N1 = 0 kg N/ha (control); N2 = 30 kg N/ha; N3 = 60 kg N/ha.

Two sites were used at the Hanang wheat farms from 1994/95–1999/2000; one was on a Mollisol and the other on a Vertisol. Two more sites were established in 1999.

Before planting, soybean seed was treated with rhizobial inoculant (Nitrosua) collected from Sokoine University, Morogoro, to induce nodulation during the early growing stages of the soybean plants.

Grass weeds in soybean were controlled by using herbicides (Fusilade at 1.0 l/ha) while the broadleaf weeds were controlled with Flex at 5.0 l/ha.

Stomp at 3.0 l/ha was used to control grass and broadleaf weeds in wheat; when necessary, 2,4-D amine or Buctril MC was used to control broadleaf weeds in wheat.

Wheat, soybeans and pigeon peas were all hand seeded. Wheat was seeded at 30 g of seed per 10 m length row (i.e., 120 kg seed/ha) while soybeans and pigeon pea were seeded at 35 kg/ha (i.e., 25 cm x 20 cm x 2 plants per hill and 50 cm x 30 cm x 2 plants per hill, respectively). This was mainly due to lack of a good seeder for such small plots at the HWC farms.

Post-harvest tillage operations were done with a chisel plough fitted with sweeps during the third week of August/ September - just after the combining operation.

Roundup application at 1.0 l/ha was done after the first rains when the first weeds to emerge were at about the 3-4 leaf stage. When necessary, a second Roundup application was done.

No appropriate herbicides were available for weed control in pigeon peas, therefore, as an alternative, hand weeding was done on the small plots.

Source of N was urea (46% N).

Net plot (harvest plot area): 3 m x 3 m
Sub-sub-plot (fertilizer plots): 10 m x 5 m
Sub-plot size (rotational sequence plots): 10 m x 15 m
Main plot size (tillage system plots): 10 m x 45 m

Data collected were as follows: straw yield (g/plot), number of wheat seedlings per m^2, plant height (cm), grain yield (t/ha), harvest index, total biomass and precipitation (rainfall and rainy days).

RESULTS AND DISCUSSION

Overall, there was a significant wheat yield difference resulting from rotation sequences. Wheat after soybean and wheat after pigeon pea gave the highest wheat yields when compared to continuous wheat plots resulting in 2.52, 2.50 and 1.80 t/ha, respectively (Table 1).

Wheat yield differences due to tillage methods were also significantly different. Overall, minimum tillage plots gave the highest wheat yields, 2.75 t/ha, followed by conventional, 2.13 t/ha, and finally zero till plots, 1.33 t/ha (Table 1).

As regards N fertilizer application, wheat yields obtained were not significantly affected by N rate; however, 30 kg N/ha gave a slightly higher yield (2.31 t/ha) than the other two levels (2.28 and 2.25 t/ha); however, all differences were not significant.

Treatment interactions of crop rotation x tillage methods or tillage methods x N-fertilizer levels or crop rotation x N rate or crop rotation x tillage methods x N-fertilizer application level were significant.

Wheat after soybean or wheat after pigeon pea, both on minimum tillage, were the best treatments as they resulted in the highest wheat yield, 2.82 and 2.80 t/ha, respectively. Also, wheat after soybean or wheat after pigeon pea with minimum tillage and application of 30 kg/ha of N resulted in significantly higher wheat yield per unit area, 2.57 and 2.54 t/ha compared to the wheat after wheat option which gave 1.05 t/ha.

CONCLUSIONS AND RECOMMENDATIONS

From the discussion above, it has been observed that crop rotation and N rate alone will not significantly improve wheat grain yields at the Hanang wheat complex farms.

Crop rotation at the HWC farms will play a significant role in sustaining wheat production at the farms. Wheat after soybean or wheat after pigeon pea, both on minimum tillage, are the best treatments as they resulted in the highest wheat yield of 2.82 and 2.80 t/ha, respectively.

Also, when crop rotation is practiced (i.e., wheat after soybean or wheat after pigeon pea) with minimum tillage and application of 30 kg/ha of N, wheat yield per unit area significantly increased to 2.57 and 2.54 t/ha.

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Questions and Answers:

Hugo van Niekerk: How long has wheat growing (continuous) been practiced at the HWC farms?

Answer: Wheat production under monocropping system (without rotation) has been practiced at the Hanang wheat farms for over the last thirty years (since the 1967/68 season).

Asefa Taa: As far as the weed spectrum is concerned, were there any differences noticed in your rotation trial?

Answer: No significant weed spectrum differences have been noticed during the four years of rotation.

Mamoun I. Dawelbeit: Results showed that there were significant differences between tillage treatments. The question is what is the main objective of tillage in the experiment? Also what are the main differences between the two tillage treatments?

Answer: The main objective of the tillage treatments was to determine a tillage method that would enhance soil moisture levels in the soil. Tillage methods were conventional, minimum and zero.

Table 1. Wheat yields (t/ha) from crop rotation trial at Hanang Wheat Complex (1994-99).

Treatment	Level	Season				
		1994/95	1995/96	1997/98	1998/99	Mean
Rotation sequence	Pigeon pea/Wheat	0.83a	2.82a	0.87a	5.37a	2.52a
	Soy/Wheat	0.79a	2.82a	1.00a	5.57a	2.50a
	Wheat/Wheat	0.84a	2.71a	0.89a	2.77b	1.80b
	C.V.(%)	27.15	13.55	21.4	9.69	17.95
	LSD(0.05)	0.1454	0.2907	0.3793	0.5904	0.35
Tillage method	Conventional till	0.82b	2.36a	0.87a	4.48	2.13a
	Minimum till	1.83a	3.55a	0.97a	4.66	2.75a
	Zero tillage	0.47c	2.19a	N/A	N/A	1.33b
	C.V.(%)	27.15	13.55	21.4	9.69	17.95
	LSD(0.05)	0.2028	1.586	0.2483	0.4793	0.63
N rate (kg/ha)	0	0.82a	2.85a	0.81b	4.63a	2.28a
	30	0.84a	2.79a	1.00a	4.59a	2.31a
	60	0.82a	2.72a	0.96a	4.49a	2.25a
	C.V.(%)	27.15	13.55	21.4	9.69	17.95
	LSD(0.05)	0.1234	0.2080	0.1359	0.3046	0.19

Table 2. Soil N status before initiation of the trial at the Gidagamowd site (Mollisol) in 1994.

Soil depth (cm)	Total N (%)	NO_3-N (ppm)	Soil moisture (%)
0-30	0.11 - 0.19	8.8 - 22.0	14.25 - 21.79
30-60	0.08 - 0.13	8.0 - 16.0	21.26 - 23.69
60-90	0.07 - 0.11	5.6 - 12.4	23.50 - 27.26

Table 3. Soil N status before initiation of the trial at the Basotu site (Vertisol) in 1994.

Soil depth (cm)	Total N (%)	NO_3-N (ppm)	Soil moisture (%)
0-30	0.11 - 0.16	10.3 - 24.6	28.91 - 35.32
30-60	0.10 - 0.15	04.4 - 22.6	32.92 - 36.49
60-90	0.09 - 0.13	02.1 - 14.6	34.06 - 38.90

ON-FARM EVALUATION OF THE RESPONSE OF FOUR BREAD WHEAT VARIETIES TO NITROGEN FERTILIZER IN KARATU DISTRICT IN NORTHERN TANZANIA

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ABSTRACT

Wheat research in Tanzania has been dominated by on-station research with an orientation for large-scale mechanized farms. This approach failed to address the real problems and constraints facing small- to medium-scale wheat farmers. Thus, an on-farm trial was established in 1997 at Rhotia and Mbulumbulu villages in Karatu district in the Northern Zone of Tanzania to evaluate the performance of three improved wheat varieties and their response to applied N fertilizer. The wheat varieties included Mbayuwayu, Kware, Tausi and a local farmers' variety; the N rates used were 0, 30, 60 and 120 kg N/ha. Combined analysis across locations and years indicated significant variety and N effects; the two- and three-way interactions were all non-significant. Across the range of wheat seed and grain prices considered in the economic analysis, the wheat variety Kware was economically optimal. Application of 30 kg N/ha was also economically optimal across a range of fertilizer and wheat grain prices. The current results provide a sound basis for recommending the wheat variety Kware and an N rate of 30 kg/ha for small-scale wheat farmers in northern Tanzania.

INTRODUCTION

Agricultural research in Tanzania has been dominated by on-station research, and the results generated by this research have often been translated into recommendations for small-scale farm production under varied environments. This approach failed to account for the actual constraints confronting the small-scale farming community. The majority of the farmers in Tanzania can be described as small-scale resource poor farmers, and these have gained little from the process of technology transfer. New technologies should be evaluated and verified under farmers' management conditions prior to making recommendations either on a national or a regional scale. Tanzanian scientists have yet to fully understand the diverse and complex environments in which resource poor farmers operate. In order to increase the relevance and, hence, adoption of agricultural interventions such technologies must be developed under farmers' conditions.

During the period between 1970 to 1994, several bread wheat varieties were released by the Selian Agricultural Research Institute (SARI) for large-scale mechanized wheat farms based at the Hanang Wheat Complex. As a result, wheat yields increased from an average of 0.5 to 8 bags/acre (Nyaki *et al.*, 1993). However, small- and medium-scale farmers have not benefited from the released wheat varieties, as well as the other components of the production package developed during that period, because there was no evaluation under the relevant environments.

Low soil fertility, exacerbated by sub-optimal farming practices such as the removal of crop

residues, overgrazing and poor soil management practices, also contributes to low wheat yields in northern Tanzania (Stonehouse and Duff, 1973). Chemical fertilizers can be used at least in part to alleviate soil fertility constraints. However, due to the rising cost of imported fertilizers, efficient nutrient sources, optimal methods of application, and wheat cultivars with high fertilizer use efficiency must be identified to minimize the cost of production.

Previous research revealed a significant response of wheat grain yield to N fertilizer in some locations in Hanang District in northern Tanzania (Nyaki *et al.*, 1993). However, the influence of N fertilizer and the relative efficiency of uptake of different wheat cultivars have not been evaluated in Karatu district. Thus, a collaborative on-farm trial, involving soil scientists and wheat breeders, was initiated in Karatu District to evaluate the performance of three recently released bread wheat varieties and their response to N rates.

The objectives of this trial included the evaluation of three improved bread wheat varieties under farmers' management conditions, the determination of an optimal rate of N fertilizer (from urea), and to promote adoption of new varieties by farmers in Karatu District based on their involvement during the growing season. This paper, therefore, presents the agronomic and economic analysis of grain yield results generated during three years of a study conducted at two locations in a major bread wheat production zone of northern Tanzania.

MATERIALS AND METHODS

The trial was initiated during 1997 and was conducted for three consecutive years at the Rhotia (3°18'28"S and 35°44'32"E) and Mbulumbulu (3°16'66"S and 35°47'08"E) villages in Karatu district of northern Tanzania. The soils in the two villages are classified as ferric Nitisols, and andic Nitisols. The soils have a mean pH of 6.5, available P of 25 ppm, total N of 0.24%, C.E.C. of 40 meq/100 g soil, and clay content of approximately 45%. Total annual precipitation is 800 mm, and that received during the growing season is approx. 550 mm. The villages are situated at altitudes of 1550 and 1500 m a.s.l., respectively.

The trial was laid out in an RCBD with a 4^2 factorial arrangement of treatments. The two factors were wheat cultivars and N rates — each having four levels. The four wheat cultivars in the trial were Mbayuwayu, Kware, Tausi — all improved and officially released cultivars — and a local farmers' variety used as a check treatment. The four N rates used were 0, 30, 60 and 120 kg N/ha in the form of urea. The trial was laid out in three replications, and the gross plot size for each treatment was 25 m^2.

Host farmers provided the necessary tillage for this trial; tillage was based on the use of tractors and sometimes ox ploughs; crop protection practices simulated farmers' practices in wheat (i.e., use of herbicides to control weeds). Pre-weighed amounts of seed (i.e., at a rate of 150 kg/ha — the mean farmers' practice) and fertilizer were broadcast applied on the soil surface of the appropriate plots after tillage, and were subsequently incorporated imitating the traditional practice. Sowing dates followed farmers' practices (i.e., sowing from the first week of April to the last week of April as soon as sufficient rain was received to saturate the surface).

At crop maturity, a net plot of 9 m^2 was harvested by sickle at ground level from each plot for grain and biomass yield determination. Grain moisture contents were determined and yields adjusted to a 12.5% moisture basis.

Statistical analysis of agronomic results. Agronomic data were subjected to analysis of

variance (ANOVA), analyzing the effects of four wheat cultivars and four N rates at each site. A combined analysis over sites and years was used to identify main and interaction effects.

Economic analysis. Grain yield data for the variety and fertilizer main effects were subjected to economic analysis, using the CIMMYT (1988) partial budget methodology. Wheat yields were adjusted downwards by 10% to more closely approximate yields on farmers' fields. Wheat cultivars and N rates were analyzed separately by calculating Gross Field Benefit (GFB), Total Costs that Vary (TCV), Net Benefit (NB), Marginal Net Benefit (MNB), Marginal Cost (MC) and the Marginal Rate of Return (MRR) for each treatment (i.e., relative to the local check in the variety analysis, and relative to the next lowest cost or non-dominated treatment for the N rate analysis).

The wheat cultivar and N treatments were also subjected to sensitivity analysis using a range of wheat seed and grain prices and wheat grain price and fertilizer prices, respectively.

RESULTS AND DISCUSSION

Results of Agronomic Analysis

Rainfall data over the three seasons in Karatu (Figure 1) reveal that the 1997 season received the highest amount of precipitation which was well-distributed up to mid July. The 1999 season exhibited a similar trend but with less total precipitation. In contrast, the 1998 season not only had the lowest precipitation during the growing season (April-August), but the rains stopped during June (i.e., before grain filling stage of the crop — contributing to terminal drought stress).

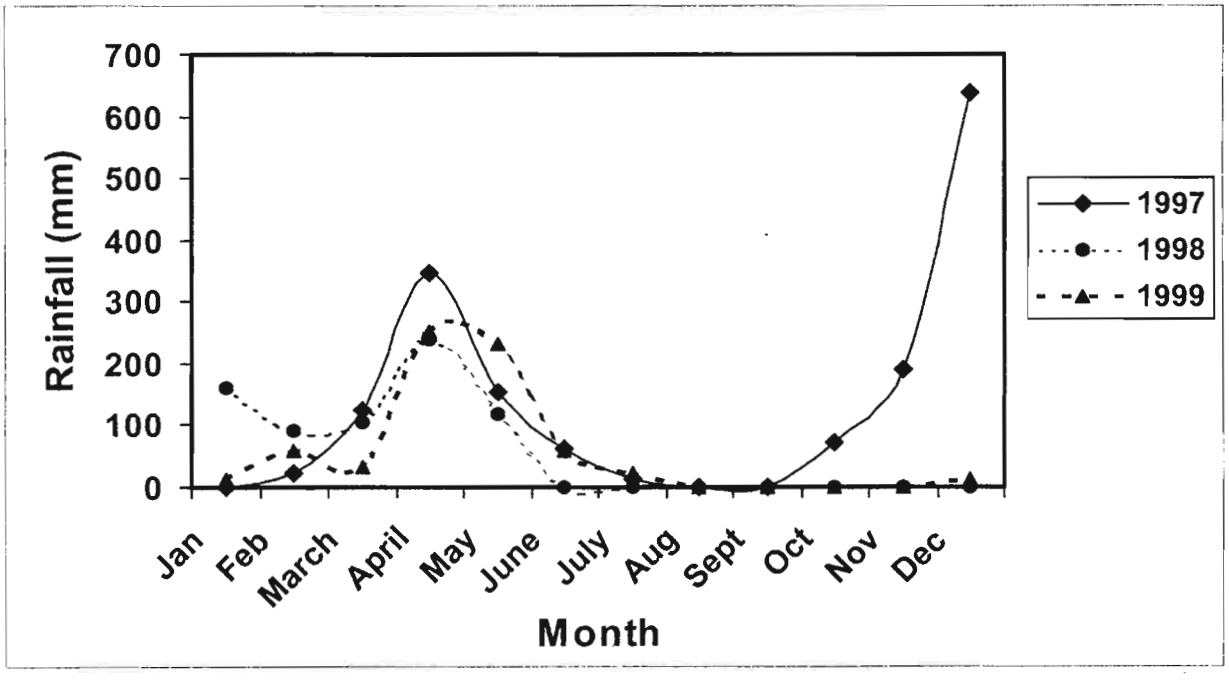

Figure 1. Rainfall received in Karatu District, 1997-1999.

The results of the ANOVA of grain yields of the two sites for the three years, and the combined analysis over years and sites are presented in Table 1. In general, wheat grain yields were higher for the improved wheat varieties relative to the farmers' local variety. Yield response to N was

evident in 1997 at both sites; however, the response was not evident in the individual analyses for 1998 and 1999 mainly due to moisture stress caused by insufficient soil moisture during the grain filling stage. In the combined analysis for the three years and over the two sites, wheat variety and nitrogen main effects showed highly significant effects on wheat grain yield. All of the two-way and three-way interactions were non-significant (Table 1).

The grain yield response of the four wheat varieties to N rates over the two sites and three years are presented in Figure 2. In general, the grain yield of the four wheat varieties responded positively to 30 kg N/ha; application of N at higher rates resulted in relatively low yield responses. The wheat variety Kware gave the highest grain yield across all N rates, while the local variety produced the lowest yield; the superior performance of Kware reflects its superiority for yield potential and presumably nitrogen use efficiency.

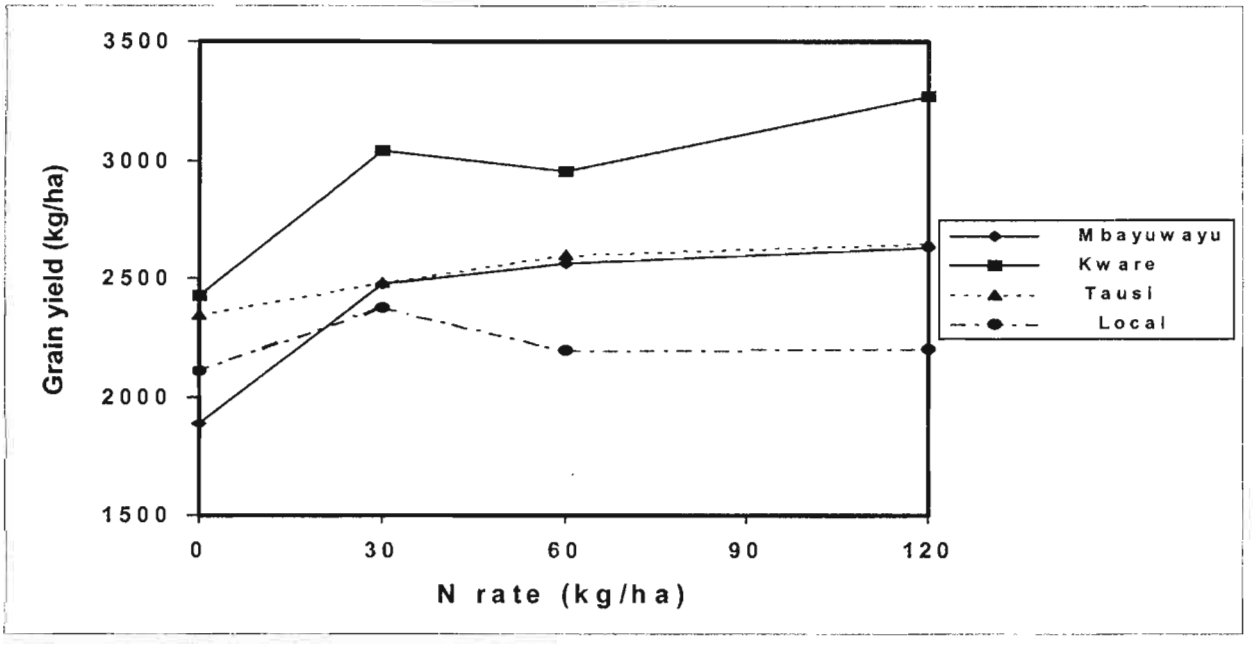

Figure 2. Grain yield response of four wheat varieties to four N rates.

Results of Economic Analysis

For the economic analysis of the four wheat varieties, it was assumed that seed of the farmers' local variety cost the same as the price of wheat grain (i.e., farmers retain their own seed), while the new varieties were priced at the cost of purchased commercial seed. This, in effect, assesses the profitability of the initial purchase of seed of the new varieties; in subsequent years, farmers would be able to retain harvested seed of the new varieties for the next season's seed requirement (i.e., until seed contamination and admixtures necessitated the purchase of "fresh" seed).

The MRR analysis of the four wheat varieties was repeated under three different price scenarios (Tables 2a, 2b and 2c). In the first scenario, an average wheat grain price (140 Tshs/kg) and an average price of wheat seed (300 Tshs/kg) were used. In the second scenario, a low wheat grain price (120 Tshs/kg) and a high price of wheat seed (350 Tshs/kg) were used. In the third scenario, an average wheat grain price (140 Tshs/kg) and a low price of wheat seed (200 Tshs/kg) were used. The results of the economic analyses were consistent with the agronomic superiority of Kware: across all three scenarios, the MRR for Kware was

close to or exceeded 100%. This indicates that it would be economically optimal for small-scale wheat producers to shift from their local wheat variety by purchasing commercial seed of Kware. On the other hand, the other two improved wheat varieties would only be economically attractive, but not optimal, if wheat seed prices are reduced to approx. 200 Tshs/kg (Table 2c).

The MRR analysis of the four N rates was repeated under four different price scenarios, varying the price of N and wheat grain (Tables 3a, 3b, 3c and 3d). The results of the MRR analysis were consistent with the agronomic analysis of N rates: across the four price scenarios, the rate of 30 kg N/ha proved to be the economic optimum. Only in the most unfavorable scenario (i.e., Table 3d — wheat grain price low and N price high) did the application of 30 kg N/ha result in an MRR below 100%; however, even under this scenario, the 30 kg N rate provided an MRR of 67% relative to nil application. In all scenarios, treatments receiving N at higher rates (i.e., 60 and 120 kg N/ha) were dominated by the 30 kg N/ha treatment (CIMMYT, 1988); that is these treatments cost more and produced a lower net benefit. Thus, the application of 30 kg N/ha appears to be a "robust" technology to recommend to small-scale wheat farmers.

CONCLUSIONS

The improved wheat varieties, particularly the variety Kware, had a marked effect on wheat grain yields across the two sites and three seasons included in the current study. Wheat grain yield increments with Kware, Tausi and Mbayuwayu varieties were 32, 14, and 7%, respectively, of the yield of the farmers' local variety. By comparison, the incremental wheat grain yields when 30, 60 and 120 kg/ha of N was applied were 18, 15, and 23%, respectively, of the yield with nil N applied.

Of the three new wheat varieties, Kware was economically optimal across a range of wheat grain and seed prices. The other two varieties were sensitive to changes in prices, and would only be attractive to small-scale farmers if wheat seed prices were significantly reduced from the current level. Application of 30 kg N/ha in the form of urea was economically optimal relative to the nil application treatment.

Small-scale wheat farmers in Karatu District should be advised to adopt the wheat variety Kware and to apply 30 kg of N/ha in the form of urea. By adopting this recommendation, farmers will increase their total wheat production and economic profits.

Further research may be required to address the anticipated long-term impact of mining soil P. On-farm studies of wheat grain yield response to P application are proposed for this area.

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Table 1. Results of ANOVA of effects of wheat varieties and N levels on wheat grain yield over sites and years.

	Rhotia			Mbulumbulu			Combined
	1997	1998	1999	1997	1998	1999	
Variety (V)	**	**	*	*	*	NS	***
Nitrogen (N)	***	NS	NS	**	NS	NS	***
V x N	NS	NS	NS	NS	NS	NS	NS
V x location							NS
N x location							NS
V x N x location							NS
Mean yield (kg/ha)	3585	1525	3226	2802	1522	2482	2513
C.V.(%)	14.6	47.6	17.8	19.1	47.9	28.0	25.5

*, **, ***: Significant at the 5, 1, and 0.1% level, respectively.
NS: Not significant ($P > 0.05$).

Table 2a. MRR analysis for the four wheat varieties at Rhotia and Mbulumbulu (1997-1999): Scenario 1.

Variety	Adj. yield	GFB	TCV	NB	MNB[a]	MC[a]	MRR[a] (%)
Local	2000	280000	21000	259000			
Mbayuwayu	2149	300860	45894	254966	-4034	24894	D
Tausi	2271	317940	46626	271314	12314	25626	48
Kware	2631	368340	48786	319554	60554	27786	218

Assumptions: Price of wheat grain = 140 Tshs/kg; Price of wheat seed = 300 Tshs/kg; Additional cost for each 100 kg wheat over local yield = 600 Tshs (cost of bag and labor).
[a]MNB, MC and MRR calculated by comparing each test variety with the local variety.

Table 2b. MRR analysis for the four wheat varieties at Rhotia and Mbulumbulu (1997-1999): Scenario 2.

Variety	Adj. yield	GFB	TCV	NB	MNB[a]	MC[a]	MRR[a] (%)
Local	2000	240000	18000	222000			
Mbayuwayu	2149	257880	53394	204486	-17514	35394	D
Tausi	2271	272520	54126	218394	-3606	36126	D
Kware	2631	315720	56286	259434	37434	38286	98

Assumptions: Price of wheat grain = 120 Tshs/kg; Price of wheat seed = 350 Tshs/kg; Additional cost for each 100 kg wheat over local yield = 600 Tshs (cost of bag and labor).
[a]MNB, MC and MRR calculated by comparing each test variety with the local variety.

Table 2c. MRR analysis for the four wheat varieties at Rhotia and Mbulumbulu (1997-1999): Scenario 3.

Variety	Adj. yield	GFB	TCV	NB	MNB[a]	MC[a]	MRR[a] (%)
Local	2000	280000	21000	259000			
Mbayuwayu	2149	300860	30894	269966	10966	9894	111
Tausi	2271	317940	31626	286314	27314	10626	257
Kware	2631	368340	33786	334554	75554	12786	591

Assumptions: Price of wheat grain = 140 Tshs/kg; Price of wheat seed = 200 Tshs/kg; Additional cost for each 100 kg wheat over local yield = 600 Tshs (cost of bag and labor).
[a]MNB, MC and MRR calculated by comparing each test variety with the local variety.

Table 3a. MRR analysis for the four N rates at Rhotia and Mbulumbulu (1997-1999): Scenario 1.

N rate (kg/ha)	Adj. yield	GFB	TCV	NB	MNB	MC	MRR (%)
0	1972	276080	0	276080			
30	2335	326900	16490	310410	34330	16490	208
60	2276	318640	32780	285860	-24550	16290	D
120	2418	338520	65360	273160	-12700	32580	D

Assumptions: Price of wheat grain = 140 Tshs/kg; Price of 50 kg bag of urea including transport = 12,500 Tshs; Application cost = 200 Tshs.

Table 3b. MRR analysis for the four N rates at Rhotia and Mbulumbulu (1997-1999): Scenario 2.

N rate (kg/ha)	Adj. yield	GFB	TCV	NB	MNB	MC	MRR (%)
0	1972	236640	0	236640			
30	2335	280200	19100	261100	24460	19100	128
60	2276	273120	38000	235120	-25980	18900	D
120	2418	290160	75800	214360	-20760	37800	D

Assumptions: Price of wheat grain = 120 Tshs/kg; Price of 50 kg bag of urea including transport = 14,500 Tshs; Application cost = 200 Tshs.

Table 3c. MRR analysis for the four N rates at Rhotia and Mbulumbulu (1997-1999): Scenario 3.

N rate (kg/ha)	Adj. yield	GFB	TCV	NB	MNB	MC	MRR (%)
0	1972	276080	0	276080			
30	2335	326900	13910	312990	36910	13910	265
60	2276	318640	27620	291020	-21970	13710	D
120	2418	338520	55040	283480	-7540	27420	D

Assumptions: Price of wheat grain = 140 Tshs/kg; Price of 50 kg bag of urea including transport = 10,500 Tshs; Application cost = 200 Tshs.

Table 3d. MRR analysis for the four N rates at Rhotia and Mbulumbulu (1997-1999): Scenario 4.

N rate (kg/ha)	Adj. yield	GFB	TCV	NB	MNB	MC	MRR (%)
0	1972	197200	0	197200			
30	2335	233500	21710	211790	14590	21710	67
60	2276	227600	43220	184380	-27410	21510	D
120	2418	241800	86240	155560	-28820	43020	D

Assumptions: Price of wheat grain = 100 Tshs/kg; Price of 50 kg bag of urea including transport = 16,500 Tshs; Application cost = 200 Tshs.

TIMING NITROGEN APPLICATION TO ENHANCE WHEAT GRAIN YIELDS IN NORTHERN TANZANIA

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ABSTRACT

Previous research on wheat production in northern Tanzania indicated that there was no grain yield response to fertilizer application during seeding. However, the reported mean wheat yield obtained by small-scale farmers was only 1.2 t/ha. In the current study, four rates of N were applied to 3 wheat varieties either during seeding or mid tillering to determine the effect of timing and rate of nitrogen application on wheat grain yield. The variety Selian 87 outyielded Viri and Mbayuwayu during one wet season. The maximum grain yield was produced by an N rate of 120 kg/ha followed by the 60 and 30 kg/ha N treatments. At Mbulumbulu, grain yield was higher with the application of all 3 fertilizer rates during mid tillering vs. seeding. Results from economic analysis indicated that farmers can produce wheat profitably by applying 30 kg/ha N at mid tillering when moisture is not limiting at that stage of development, and 60 kg/ha N during seeding when moisture is limiting.

INTRODUCTION

Nitrogen (N) plays a central role in plant biochemistry as an essential constituent of cell walls, cytoplasmic proteins, nucleic acids, chlorophyll, and a vast array of other cell components (Salisbury and Ross, 1990). Consequently, a deficient supply of N has a profound influence upon crop growth and may lead to a great loss in grain yield (Russel, 1973; Hay, 1981).

Crop response to N application varies with rate and timing of N application in relation to plant development. For wheat grown in temperate countries, grain yield response is generally maximized when N is applied prior to stem elongation (Darwinkel, 1993). This common response has been linked to the observation that crop N demand increases sharply just prior to onset of the most rapid phase of crop growth that is stem elongation. Shortage of N during this period and subsequent shoot development, lead to increased shoot mortality, and smaller spike size which limit the final number of kernels per unit area (Hay and Walker, 1989). Thus, application of N relatively early in the life cycle of wheat tends to enhance grain yield more than applications after heading. Some evidence (Darwinkel, 1993) suggests that N application should occur immediately prior to period of peak N demand or onset of stem elongation. Hay and Walker (1989) speculated that this will result in minimizing N losses from leaching.

The research work done on wheat N fertilizer in northern Tanzania has indicated that there was no grain yield advantage from N application, either applied in the seedbed or combine drilled with the seed (Nyaki *et al.,* 1993). Because of lack of consistent significant responses from fertilizer N application at the research level, wheat production in Tanzania does not utilize any supplementary N. However, the reported average wheat yield obtained by small-scale farmers

was 1.2 t/ha (Nyaki *et al.*, 1993). Nitrogen applied early may not be utilized by the plant but rather lost through leaching and or run off if there are heavy rains immediately after sowing.

The relationship of timing N application to grain yield for wheat grown in the Northern Zone of Tanzania is not well known.

Based on the above, a project was proposed with the following objectives:
1) To determine the effect of timing of N fertilization on wheat grain yield in northern Tanzania
2) To determine the optimum rate and timing of N fertilizer application to increase production at minimal cost.

MATERIALS AND METHODS

A split plot experiment with 3 replications was tested at Rhotia and Mbulumbulu in Karatu district, northern Tanzania for three years: 1997, 1998 and 1999. Three Tanzanian-developed wheat cultivars namely Viri, Mbayuwayu, and Selian 87 representing maturity ranges i) 80-90 days, ii) 110-120, and iii) 120-130, respectively, were used in the trial. The 3 varieties were broadcast at a seed rate of 150 kg/ha in 3 x 3m plots, and then incorporated into the soil by rakes. Weeds were controlled by the application of Stomp immediately after seeding and Buctril MC at mid-tillering.

Wheat cultivars used were: A_1 Viri, A_2 Mbayuwayu, and A_3 Selian 87. Rates of N application were: B_1 0 kg/ha, B_2 30 kg/ha, B_3 60 kg/ha, and B_4 120 kg/ha. Times of N application were: C_1 All at seeding and C_2 All at mid-tillering.

Data collected included: i) Number of wheat plants and weeds/m^2 at 30 days after emergence, ii) biomass and iii) grain yield in t/ha. The data were subjected to statistical analyses using MSTATC computer software. Significant treatments were separated using the Least Significant Difference (LSD) procedure.

RESULTS AND DISCUSSION

The wheat varieties tested at Rhotia, namely Viri, Mbayuwayu, and Selian 87, produced statistically similar mean grain yields of 2.28, 2.37, and 2.28 t/ha, respectively (Table 2). This was not expected in a good environment where rainfall is not limiting like Karatu, especially in 1997 and 1998 when this site received uniform rainfall (Table 5). In such an environment, Selian 87 is known to outyield Viri and Mbayuwayu because it is late maturing and utilizes the extra moisture efficiently. However, in 1997, a wet season, Selian 87 tended to outyield both Viri and Mbayuwayu. Higher grain yield was harvested in 1997 than in 1988 (Table 2). Although enough moisture was received in 1998, the 3 varieties were infected by Barley Yellow Dwarf Virus (BYD), which affected grain yield. The low grain yield in 1999 was attributed to moisture stress before grain filling. Under moisture stress, Salisbury and Ross (1990), found that abscisic acid, ABA, increased markedly in plant leaves and promoted root growth at the expense of the photosynthetic factory. In addition, Reddy (1983) reported that crop plants hastened maturity when moisture stress commenced after flowering leading to the reduction of crop duration. These two factors of reduction of photosynthetic factory and crop duration of wheat during the dry season probably had a significant effect of reducing the mean grain yield of the varieties.

The grain yield from 4 fertilizer rates used was significantly different. Maximum grain yield was produced by the application of 120 kg/ha followed by 60 and 30 producing 2.79, 2.42, and 2.21 t/ha, respectively (Table 3). Optimum response to fertilizer application on grain yield was achieved by the application of 60 kg/ha. This is also supported by the economic analysis during the dry season (Table 1a). Biomass yield was highest with the application of 120 N followed by 60 kg/ha N with mean biomass yields of 5.04 and 4.72 t/ha, respectively (Table 3). Nitrogen influences wheat grain yield through its effects upon increased leaf size and longevity (Hay and Walker, 1989). This increased biomass can be well correlated with increased grain yield as it increases the photosynthetic factory.

At Mbulumbulu site, the 3 varieties produced comparable mean grain yield. Mbayuwayu followed by Viri and Selian 87 produced 1.74, 1.65, and 1.65 t/ha, respectively. At this site, the 4 fertilizer rates showed a positive interaction with the 2 periods of N application. The mean grain yields from each of 4 rates of N application during mid-tillering and seeding were comparable. However, examining the yield for the wet seasons in 1997 and 1998 and dry season in 1999 separately, indicated that moisture was the major factor in determining wheat yield. The grain yield was higher when fertilizer was applied during mid-tillering during the wet seasons. The optimum yield advantage of 0.26 t/ha was achieved when 30 kg/ha N was applied during mid-tillering as compared to at seeding (Table 4). Grain yield response to higher rates of N fertilizer application during the wet seasons was a consequence of prolonged rainfall intensity, which caused leaching of nitrates beyond the root zone. The loss of nitrates was higher when the fertilizer was applied at seeding than at mid tillering, which was reflected in grain yield (Table 4).

In contrast, when moisture was limiting as in 1999, the grain yield from each of 4 fertilizer rates during seeding was higher than at mid-tillering. The optimum yield advantage of 0.31 t/ha was achieved when 60 kg/ha was applied at seeding as compared to mid-tillering (Table 4). Moisture is needed as a medium in which dissolved nutrients can be moved to the crop roots. When moisture was limiting, the applied N at mid-tillering was not effectively used by the plant because after flowering wheat plants hasten their maturity and crop duration is reduced. When fertilizer was applied during seeding, moisture was not limiting and it was efficiently utilized by the crop (Table 4).

Nitrogen is important in determining the final grain yield of wheat during the rapid phase of crop development because it is required for higher rates of spikelet initiation, improvement of spikelet fertility, and increasing grains per fertile spikelet (Frank and Bauer, 1982) and for biomass formation (Peterson and Frye, 1989). Although 120 kg/ha N was enough for spikelet fertility, this amount might have been excessive which could have created lodging and tiller mortality decreasing the final biomass yield for mid-tiller N application (Table 4).

For economic analysis of applied N, a wheat farm gate price of 120 TShs/kg of wheat was used; 610 TShs/kg N; labor for fertilizer application on 1 ha cost 125 TShs.

For the farmer to accept the technology (applying fertilizer to wheat), the MRR should not be less than 70%. The highest MRR was obtained by the application rate of 30 kg/ha N during seeding (Table 1a). However, for farmers who use 0 N, investing in 30 kg/ha N gives a very high return, but if these farmers stopped at 30 kg/ha N, they would miss the opportunity for further earnings at an attractive rate of return by investing in an additional 30 kg/ha N. These farmers will continue to invest as long as the return to each extra unit of N invested, as measured by the MRR, are higher than the cost of extra unit invested. Based on the above,

farmers of Mbulumbulu will invest profitably by applying 60 kg/ha N to wheat production when moisture is limiting. However, when moisture is not limiting, applying 30 kg/ha N during mid-tillering is profitable (Table 1b).

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Questions and Answers:

Wolfgang H. Pfeiffer: (1) With 30 kg N/ha, biomass increased by 0.4 t/ha; moving from 30-60 N produced +0.6 t/ha. Since straw is of economic value, should the value of straw + grain be taken into account for N recommendation and in economic analysis? (2) Why no split application of N, e.g. 25%/75%?

Answer: (1) Straw in Karatu district does not have any economic value. After harvesting, straw is left to be eaten by free-range animals. (2) Split N application currently being tested by my colleague.

Omer H. Ibrahim: In studies addressing timing of fertilizer N application, it is essential to define the soil type to reach solid recommendations.

Answer: Yes. I agree with you! The soil type of the sites where the experiment was conducted was Nitosol.

Izzat S.A. Tahir: Your economic analysis showed that using 60 kg/ha N at seeding under moisture-stressed conditions is the best. Do you advise farmers to use more nitrogen under these conditions rather than the 30 kg/ha N under normal conditions?

Answer: No! I don't advise farmers to use more N under stressed conditions: 60 kg/ha N during seeding in this experiment yielded higher probably because moisture was available after seeding, but was not available at mid-tillering.

Table 1a. Economic analysis of applying nitrogen to wheat during dry season 1999.

N rate (kg/ha)		Grain (kg/ha)	FB (TShs)	TCV (TShs)	NB (TShs)	MC (TShs)	MNB (TShs)	% MRR
0	Seeding	1190	142800	0	142800	NA	NA	
0	Tillering	1170	140400	0	140400	NA	NA	
30	Seeding	1620	194400	18425	175975	18425	33175	180
30	Tillering	1350	162000	18425	143575	18425	3175	17
60	Seeding	1880	225600	36725	188875	18300	12900	70
60	Tillering	1472	176640	36725	139915	18300	D	
120	Seeding	1930	231600	73325	158275	36600		
120	Tillering	1570	188400	73325	115075	36600		

Table 1b. Economic analysis of applying nitrogen to wheat during wet season in 1998.

N rate (kg/ha)		Grain (kg/ha)	FB (TShs)	TCV (TShs)	NB (TShs)	MC (TShs)	MNB (TShs)	% MRR
0	Seeding	1370	164400	0	164400	NA	NA	
0	Tillering	1370	164400	0	164400	NA	NA	
30	Seeding	1790	214800	18425	196375	18425	31975	173
30	Tillering	1860	223200	18425	204775	18425	40375	219
60	Seeding	1910	229200	36725	192475	18300	D	
60	Tillering	1970	236400	36725	199675	18300	D	
120	Seeding	2150	258000	73325	184675	36600		
120	Tillering	2280	273600	73325	200275	36600		

Table 2. Mean grain yield (t/ha) of 3 wheat varieties over 3 years at Rhotia averaged over 4 rates of N and 2 application timings.

Variety	1997	1998	1999	Mean
Viri	3.36	1.90	1.58	2.28
Mbayuwayu	3.28	2.00	1.82	2.37
Selian 87	3.44	1.80	1.61	2.28
Mean	3.36	1.9	1.67	2.31
LSD(0.05)	0.68	0.63	0.45	0.66
C.V.(%)	8.21	21.49	13.91	19.43

Table 3. Mean biomass and grain yield (t/ha) over 3 years at Rhotia averaged over 3 varieties and 2 application timings.

N rate (kg/ha)	1997	1998		1999		Mean	
	Grain	Biomass	Grain	Biomass	Grain	Biomass	Grain
0	2.19	3.33	1.53	4.02	1.54	3.68	1.75
30	3.35	3.95	1.70	4.22	1.59	4.09	2.21
60	3.71	5.07	2.01	4.37	1.55	4.72	2.42
120	4.19	5.32	2.44	4.75	1.75	5.04	2.79
Mean	3.36	4.42	1.92	4.34	1.60	4.38	2.29
LSD	0.51	0.85	0.33	0.38	0.32	0.55	0.52
C.V.(%)	8.21	18.71	21.49	13.16	13.91	19.44	13.46

Table 4. Mean biomass and grain yield (t/ha) over 3 years at Mbulumbulu averaged over 3 varieties.

N rate (kg/ha)		1997	1998		1999		Mean	
		Grain	Biomass	Grain	Biomass	Grain	Biomass	Grain
0	Seeding	3.04	3.47	1.38	3.20	1.19	3.34	1.87
0	Tillering	3.00	3.94	1.39	3.26	1.24	3.60	1.88
30	Seeding	4.10	4.46	1.79	4.11	1.62	4.29	2.50
30	Tillering	4.55	4.71	1.86	3.66	1.34	4.19	2.58
60	Seeding	4.51	4.58	1.91	4.87	1.78	4.73	2.73
60	Tillering	4.56	4.83	1.97	4.00	1.47	4.42	2.67
120	Seeding	4.60	6.29	2.15	5.01	1.93	5.65	2.89
120	Tillering	4.77	5.80	2.28	4.20	1.57	5.00	2.87
Mean		4.14	4.76	1.84	4.04	1.52	4.40	2.49
LSD		0.24	1.38	0.36	0.38	0.10	0.14	0.22
C.V.(%)		5.76	29.81	20.16	19.38	9.44	24.54	17.88

Table 5. Rainfall data (mm) for 3 years at Rhotia, Karatu District, Northern Tanzania.

Month	1997	1998	1999
January	0	159.8	11.8
February	24.5	91.6	58.5
March	122.5	105.5	32.5
April	347.8	237.9	252.9
May	154.4	158.9	232.4
June	62.9	0	59.3
July	13	0	22.1
August	0	0	0
September	0	0	0
October	70.6	0	0
November	189.6	0	0
December	638.6	0	11.5

DELAYED NITROGEN APPLICATION AND LATE TILLER PRODUCTION IN WHEAT GROWN UNDER GREENHOUSE CONDITIONS

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ABSTRACT

Delaying application of N to wheat until the time of heading or beyond increased grain protein content rather than grain yield. In a previous unreported glasshouse experiment by the current authors, application of high amounts of N (700 mg N pot^{-1} of 2 l volume) at the time of anthesis stimulated the production of fresh tillers in the post-anthesis period in spring wheat. This phenomenon is not of common occurrence. The current study examined the levels of tissue N concentration in the post-anthesis period that triggered late tiller production; it also examined the grain production potential of these late tillers, by providing them with adequate moisture under glasshouse conditions even after early season tillers had reached maturity. In two treatments in the glasshouse, N was applied at 250 and 700 mg pot^{-1} at sowing. In six other treatments, 250 mg N pot^{-1} was applied at sowing and a second dose of 450 mg N pot^{-1} was applied at 0, 5, 10, 15, 20 and 30 days after anthesis. Stimulation of late tiller production occurred when N was applied at any time during the first 30 days after anthesis. However, the contribution of late tillers to grain yield $plant^{-1}$ declined as the time of N application was delayed post-anthesis. Also, the leaf N concentration at which the production of late tillers was stimulated varied according to the time of N application in the post-anthesis period. Of all the split treatments, application of N at anthesis produced the largest grain yield per plant due to a 36% contribution from late tillers. We conclude that late tillers can make a useful contribution to grain yield $plant^{-1}$ under glasshouse conditions. However, the long time lag between the maturity of early and late season tillers may pose practical difficulties to harvesting, even if the same phenomenon were to be duplicated under field conditions.

INTRODUCTION

Application of N fertilizer generally increases the grain yield of wheat (Ellen and Spiertz, 1980; Benzian and Lane, 1981) and the responses are high if the N is applied early in the season, e.g., up to the time of tillering and commencement of stem elongation when crop demand is greatest (Mossedaq and Smith, 1994). When applied around anthesis, with adequate moisture under field conditions, however, grain protein is increased (Strong 1982; Smith *et al.*, 1989; Randall *et al.*, 1990), but yield responses are poor (Mossedaq and Smith, 1994). Previous unreported glasshouse observations by the current authors, showed that high rates of N application near the time of anthesis, stimulated the production of fresh tillers in the post-anthesis period, in a spring wheat cultivar 'Hartog' grown in pots. As these late tillers were presumed to be nonproductive, watering was terminated when the early season tillers senesced, and hence the late tillers did not

contribute to grain yield. The importance of these late tillers to grain development, which was not examined in that experiment, forms the basis for this study, in view of the reported poor grain yield responses to N applied late in the season (Mossedaq and Smith, 1994).

In this study a serial application of N at anthesis and the 30 day period thereafter was examined. The objectives were:

a) to establish the levels of post-anthesis shoot N concentration that stimulate the production of late tillers, and
b) to examine the contribution of late tillers to grain yield under well-watered conditions in the glasshouse.

MATERIALS AND METHODS

Free draining 2.5 l plastic bags were filled to within 2 cm of the top with a mixture of peat moss and sand (2:3 v/v) and a nutrient solution which excluded only N. Calculated amounts of ammonium nitrate, dissolved in water, were added during mixing, according to the N treatments below.

Wheat cv. Hartog was grown in a greenhouse at a controlled day/night temperature of 18/13 °C and eight N treatments were imposed. In two treatments, N was applied at 250 and 700 mg pot^{-1} at the time of sowing. In the other six treatments, 250 mg was applied at the time of sowing, and the second dose of 450 mg N pot^{-1} was applied at 0, 5, 10, 15, 20 and 30 days after anthesis. These treatments are subsequently referred to as A0, A5, A10, A15, A20 and A30, respectively. The experiment was set up as a randomized complete block design with 3 replicates. Each treatment within a block comprised eight pots. Six seeds were sown pot^{-1} and thinned to three plants one week after seedling emergence. A series of harvests was made at anthesis, 10, 15, 20, 25, 30, 40 and 54 days after anthesis (DAA) and at maturity (including maturity of late tillers at 114 DAA). The first harvest of treatments A0 through to A30 was made 10 days after each treatment commenced. Plants were adequately watered until the final harvest.

Determination of Dry Matter and Nitrogen Concentration

At each harvest, plant samples were separated into green leaf, culm and grain (where applicable). All plant parts were dried separately at 70 °C for 48 h, weighed and their N concentrations determined using a micro-Kjeldahl procedure. Only leaf N concentration is reported in this text.

RESULTS AND DISCUSSION

Nitrogen Concentration in Shoot and Tiller Production

Stimulation of late tillers occurred when N was applied at any time during the first 30 days after anthesis. Also, the leaf N concentration at which the late tillers were stimulated varied according to the time of N application in the post-anthesis period (Table 1). Indeed, tissue N at 15 DAA in the green leaf in treatment A0, for example, was 4.2% in comparison with values less than 3% in N250. With the last N application (A30), green leaf N was only about 2.8% at 55 DAA, corresponding to 15 days after N application in that treatment, yet tillers were still produced. Again, by that time N250 had almost completely senesced. Thus, with delayed N applications, the leaf N concentration at which late tiller formation was stimulated, was lower than similar applications close to the time of anthesis.

Tiller Production

Late tiller production occurred when N was applied at any time during the first 30 DAA. Also, in the split N treatments, the time of N application had little influence on the number of late tillers produced. However, there were more productive late tillers when N was applied at anthesis. (Table 2).

Grain Yield

When N was applied at sowing, total grain yield per plant increased from 3320 mg in N250 to 5934 mg in N700 (Table 3). Such responses to N are commonly reported (Spiertz and Ellen, 1978; Strong, 1982). With split treatments, application of N from anthesis until 15 DAA produced the highest grain yield per plant due to the relatively large contribution of grain by late tillers (Table 3), which provided up to 36% of the total yield per plant as in A0. However, the percentage contribution by the late tillers declined in A30. Such grain yield production by late tillers is not commonly reported. Instead, late application of N has been associated with increased grain N content — which was also observed in this study. The contribution by main stems or early productive tillers generally did not differ between the split treatments ($P>0.05$). Production of late tillers has reportedly occurred when wheat plants were recovering from water deficits (Talukder *et al.*, 1987). In this experiment and that of Talukder *et al.* (1987), it is less likely that increase in water or N supply would cause differentiation of cells in the stem into tiller initials. Instead, it is possible that the tiller initials were present in a latent state and were stimulated to grow in response to the extra assimilates from photosynthesis.

CONCLUSION

We conclude that plants can absorb N that is applied late in the growing season. This N can increase tissue N concentration when applied within 30 days after anthesis. Nitrogen application after anthesis is also capable of stimulating the production of late tillers, perhaps when the plant reaches a critical N concentration after anthesis; these tillers can contribute up to a 36% increase in grain yield in pots. Such a response to an anthesis or post-anthesis N application does not appear to be of common occurrence in wheat, which is characterized as a determinate crop. If the greenhouse results were duplicated in the field, the long time lag, up to 40 days, between maturity of early and late season tillers would pose practical problems to mechanical harvesting.

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Table 1. Nitrogen concentration (%) of green leaf of wheat 10-15 days after fertilizer application for a particular treatment during the post anthesis period.

Treatment	Days after anthesis						
	0	10	15	20	30	40	54
N250	2.8						
N700	4.8	3.0	2.6	2.8	1.7	1.5	-
A0	4.8	4.5	4.2	4.2	3.9	2.3	2.3
A20	-	4.0	4.2	4.1	3.5	2.3	2.7
A30	-	-	-	-	-	2.2	2.8

Table 2. Effect of nitrogen on the number of productive tillers and late tillers of wheat cv. Hartog under controlled temperature greenhouse conditions.

Treatment	Tiller numbers		
	Main stem + early tillers	Late productive tillers	Total late tillers
N250	2.1	-	-
N700	3.2	-	-
A0	2.2	2.7	2.7
A5	2.2	1.9	1.9
A10	2.1	1.4	1.4
A15	2.0	1.7	1.4
A20	2.1	2.1	1.9
A30	2.0	1.4	2.5
$LSD_{(0.05)}$	0.52	NS	NS

Table 3. Effect of nitrogen on the grain yield of main stems, early productive tillers and late tillers of wheat cv. Hartog grown under controlled temperature greenhouse conditions.

Treatment	Grain yield (mg plant^{-1})			
	MS	EPT	LPT	Total
N250	1896	1425	0	3320
N700	2338	3596	0	5934
A0	2804	1833	2595	7232
A5	2456	2078	1238	5773
A10	2850	2138	728	5786
A15	2704	1913	1132	7544
A20	2761	2086	501	5344
A30	2244	1507	642	4392
LSD ($p<0.05$)	567	1074	871	987

MS: Mean stem; EPT: Early productive tillers; LPT; Late productive tillers.

RESPONSE OF WEED INFESTATION AND GRAIN YIELD OF WHEAT TO FREQUENCY OF TILLAGE AND WEED CONTROL METHODS UNDER RAINFED CONDITIONS AT ARSI NEGELLE, ETHIOPIA

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ABSTRACT

Weed infestation results from poor land preparation, often as a result of a shortage of labor and/or oxen. Research was conducted at Arsi Negelle in southern Ethiopia to evaluate the effect of repeated tillage and weed control methods on weed infestation and grain yield of wheat for three consecutive seasons from 1996-1998. Five tillage practices (zero-till, one, two, three, and four plowings) were compared under four weed control methods (Duplosan at 2.5 l/ha, Duplosan together with one handweeding at 30 DAE, one handweeding at 30 DAE, and two handweedings at 30 and 60 DAE). Broadleaf weeds comprised 73% of the total weed population. Repeated tillage reduced weed infestation and increased the grain yield of wheat. Weed density was 79 and 34% higher under zero-till and three plowings in comparison to four plowings. The yields from two (1257 kg ha^{-1}) and three plowings (1795 kg ha^{-1}) were 42 and 18% lower, respectively, than four plowings. Weed infestation was negatively correlated with tillage frequency (r=-0.96) and grain yield (r=-0.98). Multiple regression analysis indicated that 83, 88 and 61% of the total variation in yield during 1996, 1997 and 1998, respectively, was attributable to tillage. Handweeding twice reduced weed populations and increased grain yield, while plots treated with Duplosan alone had 49% more weeds. In conclusion, the highest frequency of tillage reduced weed infestations and increased grain yield.

INTRODUCTION

Wheat is a major crop in the Arsi Negelle and Shashemene areas at altitudes near 1,990 m a.s.l., and covers about 13.7% of the total cultivated area. Shortage of oxen and labor constrain wheat production. A pair of oxen is needed to till the land well, but many farmers own only a single ox and fail to prepare the land well. Often farmers practice 2 to 3 plowings for wheat planting (Yohannes, 1982), and this has increased infestation of both broad leaf and grass weeds resulting in low productivity of wheat. Under such condition, wheat grain yield ranges from 600 to 2500 kg ha^{-1}, in fact, depending on soil type, weather conditions and crop management factors. Tillage practices vary with prevailing weather conditions and influence soil moisture (Kamwaga, 1989; Johnson *et al.*, 1989). Various studies indicate that repeated tillage creates conducive conditions for better plant growth and grain yield. Getinet (1988) reported four plowings either on red or dark gray soil produced higher grain yield of wheat. The study by Dhinam and Sharma (1986) as cited by Majid *et al.* (1988) showed that six plowings in comparison with five and no-till resulted in a higher grain yield of wheat. Jongdee (1994) and Dawelbeit and Salih (1994) reported similar results. The reason for higher yield of wheat, according to Jongdee (1994), was due to lower bulk density and

superior root growth, which indirectly increased grains/spike, biomass and grain yields.

Repeated tillage stimulates weed seed germination before the final tillage and reduces the seed bank and subsequent weed densities (Johnson et al, 1989). The findings of Dorado *et al.* (1998), Thompson and Whitney (1998) and ICARDA (1984) showed that weed density was more in no-till plots than from repeated plowings. Weed infestation due to repeated tillage was reduced by more than 50% compared with zero tillage (ICARDA, 1984).

The result achieved by Thompson and Whitney (1998) showed poor crop stands from no-till plots. Similarly, Kreuz (1993) in his investigation has obtained lower seedling density, number of spikes m^{-2}, and straw yields from zero-till plots. Wallace and Bellinder (1989) found decreased potato stand by 16% with reduced tillage when averaged over seasons. The report of the above-mentioned researchers showed that the yield of potato in reduced plots decreased an average of 22% compared to yields in conventionally tilled plots while in other years no difference was detected between tillage systems. On the contrary, reduced tillage and zero-till can produce a similar yield as that of repeated tillage provided that straw mulch is applied. Aulakh and Gill (1988) reported that zero tillage, due to retention of crop residue on top of the soil, had more yield and lower bulk density than conventional tillage. Zero tillage applied with straw mulch had more grains/spike and gave similar grain yields of wheat as compared to repeated tillage of 6 to 8 plowings (Majid *et al.* (1988). The reason for the better performance of zero till was due mainly to uniform placement of seeds, which resulted in better plant emergence and less weed infestation than the conventional. Brecke and Shilling (1996) indicated higher yield from zero till due to reduced weed competition. Stobbe (1989) and Jongdee (1994) advocated the importance of straw mulch in minimum (zero) tillage for better performance and grain yield of wheat. Other researchers (Aulakh and Gill, 1988) also confirmed that due to retention of crop residue on the soil, yields from zero tillage were higher and soil bulk density was lower than the conventional tillage.

Minimum tillage can cost less since the power and time requirement is minimal (Dawelbeit and Salih, 1994; Stobbe, 1989). In addition, minimum tillage allows earlier planting, reduces soil erosion and there can be less potential for pesticide contamination of surface water (Brecke and Shilling, 1996). The result achieved by Macharia *et al.* (1997) showed that significant difference was not detected on wheat yield due to tillage systems in the first three consecutive seasons. Kamwaga (1989) found no significant variation in yield between the conventional and other tillage practices for two years at various locations because of well distributed precipitation. He noted that with erratic rainfall, minimum tillage could produce higher grain yield of wheat.

The overall objective of this study was, therefore, to investigate the effect of repeated tillage and weed control on weed infestation, growth and grain yield of wheat.

MATERIALS AND METHODS

The study was conducted at Arsi Negelle in the Southern Region of Ethiopia for three consecutive years, 1996-98. The wheat variety, Dashen, was sown at a seed rate of 125 kg ha^{-1}. Diammonium phosphate was applied at planting to supply 18 and 20 kg ha^{-1} nitrogen and phosphorus, respectively. Tillage was with the traditional ox-drawn plow. Glyphosate was applied at 4.5 l ha^{-1} 15 to 20 days before sowing for the zero-tillage plots. Seed was drilled with 20 cm row spacing. For the zero-tillage, seed was sown in furrows made using hoes, and fertilizer was side banded. Planting dates were 22 July 1996 and 1997, and 4 Aug.

1998.

The treatments were: plowing frequency (no-till, 1, 2, 3,and 4 plowings at an interval of 15 days for the repeated plowings); and weed control methods (D2.5 = Duplosan at 2.5 l/ha, D2.5 +1HW = Duplosan plus one hand weeding at 30 days after emergence (DAE); 1HW = one hand weeding, and 2HW = Two hand weedings at 30 and 60 DAE). The plot size was 15 rows with 0.2 m row spacing by 5 m length. Data on weed types and population m^{-2}, plant height, spike length, grains per spike, kernel weight, biomass and grain yields were taken. A quadrat of 25 by 25 cm was used for weed count and the population was averaged over four throws for each plot.

DMRT was used to differentiate treatment means (Gomez and Gomez, 1983). Simple correlation and multiple regression analysis were made. The model used for multiple regression analysis was:

$$Y = a + b_1T + b_2W,$$

where Y = grain yield (kg ha^{-1}), T = tillage frequency, and W = weed control method.

RESULTS

Moisture stress was severe during 1998 crop season with intermittent shortages of rainfall beginning at sowing time, and this seriously affected the crop. Precipitation was plentiful in 1996 and adequate in 1997. Under the moisture stress conditions of 1998, plots plowed three and four times had relatively better growth and grain yield, possibly due to conservation of soil moisture and reduced weed competition.

Weed type and population density: Broadleaf weeds dominated and comprised about 73% of the total weed population. The major weeds observed were *Galinsoga parviflora, Bidens pilosa* and *Nicandra physalodes* (Table 1). Weed population varied between the two years of this study. The reduction in weed density with increased tillage was significant in 1997. The respective mean increases of weed population in zero-till and two plowings over four times were 79 and 59%. Four plowings had the lowest weed infestation in each level of weed control. Frequency of plowing is negatively correlated with weed population (Fig. 1). The lowest weed population density was observed on plots weeded twice. Weed density was 49 and 24% more in plots treated with Duplosan (D2.5 and D2.5 + 1HW) as compared with two weeding, respectively (Fig. 4).

Plant height (cm): Plant height increased as the number of plowings increased, and the mean height was 16 and 6 cm more with four plowings as compared to two and three, respectively. This was consistent across seasons and is attributed to better seedbed preparation and reduced weed competition in all growing seasons. Plant height had a positive and significant association with spike length, biomass and grain yields but a negative correlation with density of weeds (Table 2). With greater plant height, spikes were longer and more biomass was produced.

Spike length (cm): In 1997 and 1998, spike length increased with the number of plowings. The mean spike length was 42, 33 and 14% greater for four plowings as compared to no-till, one and two plowings, respectively (Fig. 2).

Thousand-kernel weight (TKW) and grains/spike: Kernel weight was more in one and two hand weedings during 1997. Number of plowings did affect TKW. Grains per spike were more with four plowings and grains/spike were 50, 25, and 11% less in zero till, two and three plowings, respectively.

Biomass yield: Wheat biomass increased with more plowing. Even under serious moisture stress (1998), repeated plowing increased the biomass both in the three and four plowings (Fig. 2). The average increases in biomass from four and three plowings over two were 154 and 92%, respectively.

Grain yield: In all seasons, yield increased as frequency of plowing increased even under low moisture conditions of 1998. Significant yield variations among zero-till, one and two plowings were not observed in 1997 and 1998. Yields were 58, 54, 42 and 18% less in no-till, one, two and three plowings, respectively, in comparison to four plowings, which gave, averaged over weed control and seasons, 2180 kg ha^{-1} (Fig. 3). Grain yield was positively correlated with plant height, spike length, grains per spike and biomass yield, while density of weeds was negatively correlated with grain yield (Table 2). Frequency of tillage was linearly associated with grain yield and 83, 88 and 61% of the total variation in grain yield during 1996, 1997,and 1998, respectively, was mainly attributed to frequency of tillage (Table 3). The highest yield (1517 kg ha^{-1}) was obtained from plots weeded twice (Fig. 4). The yields obtained from the application of Duplosan 2.5 l ha^{-1} alone and its combination with one hand weeding were 9 and 5% less as compared to hand weeding twice while weeding once gave 1386 kg ha^{-1}.

DISCUSSION

Repeated tillage created conducive conditions and favored plant establishment, growth and production. Dawelbeit and Salih (1994), Getinet (1988), and Chugunov *et al.* (1988) reported advantages of tillage frequency, including good seedbed preparation. Our results confirm that more plowing results in better growth and thus faster plant development probably because of reduced crop-weed competition and possibly better root growth. Weed density was less probably due to reduced weed seed numbers in the soil with repeated plowing. The reports of Thompson and Whitney (1998), Johnson et al. (1989), and ICARDA (1984) also showed low weed infestation in conventional (repeated) tillage. Thompson and Whitney (1998) reported high weed density, poor emergence and increased weed competition with zero-tillage. The result of Majid et al. (1988), and Brecke and Shilling (1996), however, showed low weed population in minimum tillage. Brecke and Shilling (1996) indicated more weed biomass of sicklepod (45% greater) in conventional cf. no tillage. Weed population of redroot pigweed was found to increase in reduced tillage as compared to conventional tillage (Wallace and Bellinder, 1989).

Hand weeding twice was found to be effective in controlling weed infestation and increased grain yield of wheat. Other findings (ICARDA, 1984) also detected that handweeding was most effective for weed control and reduced weed infestation and dry weight of weeds and was better than chemical weed control. However, significant variation in yield of wheat was not observed between hand weeding and chemical control. Chugunov et al. (1987) also reported reduced weed population and higher yield of wheat due to twice handweeding. The negative association between tillage frequency and weed population shows the response to repeated tillage in reducing weed density, which negatively affected grain yield. Kreuz (1993) reported that no-till significantly reduced seedling density, spikes m^{-2}, and straw yield

and had no effect on grain yield of wheat which is contrary to our result, which showed significantly lower yield in no-tillage. Kreuz did find that biomass yield was significantly reduced in no-till plots. The result of this study shows that because of favorable conditions created by repeated plowing, there was greater plant height, more biomass and less weed infestation and this had a positive effect on grain yield of wheat.

This study is not in line with the findings of Aulakh and Gill (1988) where they reported the non-significance of tillage system (conventional and no tillage) on plant height and seed weight of wheat. In this study, repeated tillage helped in reducing weed competition for moisture which probably was important in 1997 and 1998 resulting in improved yield and yield-related characters of wheat. Probably repeated tillage, besides reducing weed competition, helped *in situ* soil moisture conservation, in particular in stress periods, which was utilized by wheat that produced higher grain yield. This is reflected by the positive response in plant height, spike length, grains/spike, and biomass yield which have positive significant correlations with yield. In contrast Dorado et al. (1998) obtained better barley yield under drier conditions with reduced tillage. The findings of Jongdee (1994) and Dhinam and Sharma (1986) indicated that repeated plowing increased the biomass of wheat. Because of reduced weed competition for moisture and soil nutrients and presumably *in situ* moisture conservation that resulted from repeated tillage, there were better seed emergence and more yields. In general, tillage frequency had a positive and significant effect on yield and yield-related characters of wheat.

Weed infestation, which is the result of poor land preparation and unavailability of labor to weed on time, is one of the major production constraints in wheat field. This study showed that repeated tillage reduced weed infestation and increased plant height, biomass and grain yields. Because of reduced crop-weed competition even during moisture stress periods, there was a positive crop response to frequency of tillage, which is reflected by an increase in yield. The yield loss decreased as frequency of plowing increased. Poor crop performance was observed on minimum tillage treatments (zero-till and one-time plow) that resulted in low yield particularly as moisture stress became severe.

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Table 1. Weed species observed during the experimental seasons, 1996-1998, Arsi Negele, Ethiopia.

Weed species	1996	1997	1998
Broad leaf weeds			
Plantago lanceolata	*		*
Galinsoga parviflora	*	*	*
Bidens pilosa	*	*	*
Commelina benghalensis	*	*	
Nicandra physalodes	*	*	*
Guizotia scabra		*	*
Anagalis arvensis	*	*	
Grassy weeds			
Eragrostis spp.	*	*	*
Couch grass		*	

* = Weeds observed during the season.

Table 2. Simple-correlation analysis of grain yield with yield-related components.

Parameter	R value (n = 5)		
	Season		
	1996	1997	1998
Plant height (cm)	0.906*	0.990*	0.926*
Weeds m^{-2}	-0.119	-0.982*	-
Seed weight (g)	-0.717	0.863	-0.581
Spike length (cm)	-	0.881*	0.831
Seeds/spike (no.)	-	0.936*	-
Total biomass (kg m^{-2})	-	0.997**	0.969**

*, ** Indicates significance at the 5 and 1% probability levels, respectively.

Table 3. Multiple regression analysis of tillage by weed control method experiment on grain yield (kg ha^{-1}).

Season	Regression equation	R^2
1996	$Y = 1948+302.5x_1-14.3x_2$	0.827
1997	$Y = 65.7+600.9x_1+108.8x_2$	0.875
1998	$Y = 166.6+84.6x_1+0.4x_2$	0.613

Note: X_1=tillage frequency
X_2=weed control method

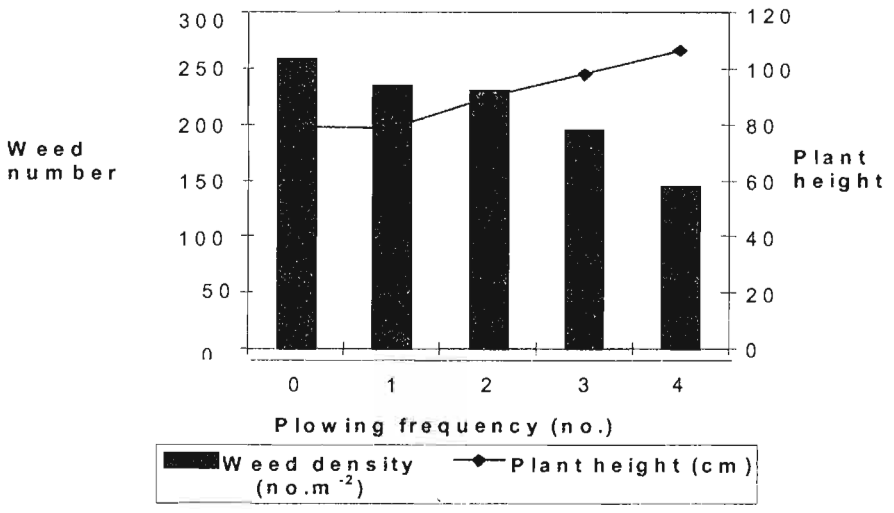

Fig. 1. Response of weed density and plant height (1996-97) to frequency of tillage, Arsi Negelle, Ethiopia.

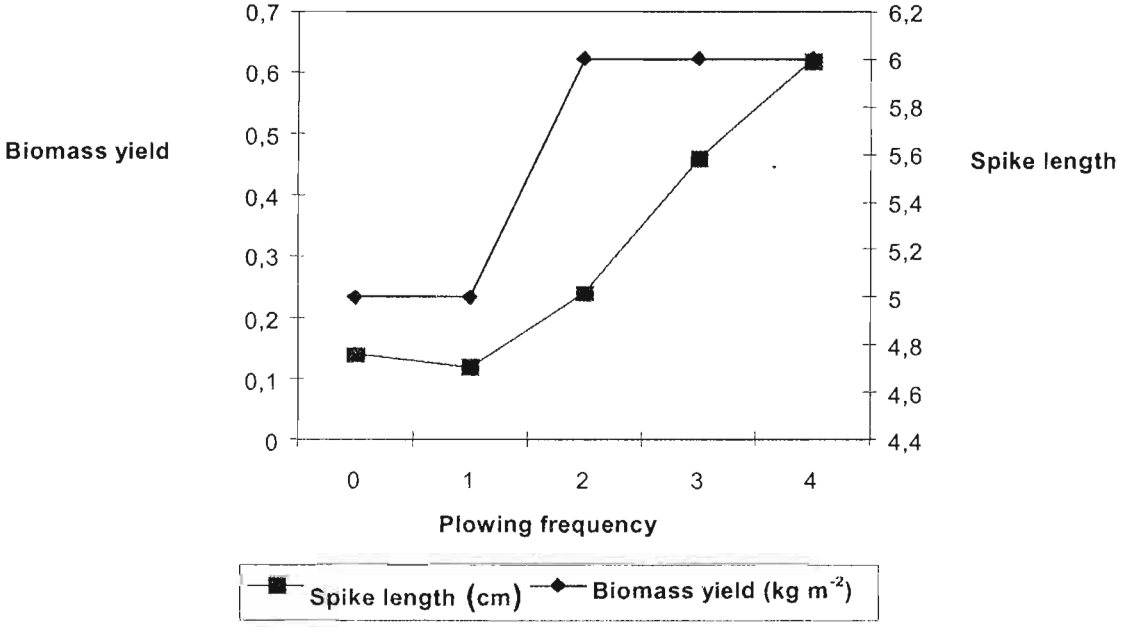

Fig. 2. Response of spike length and above-ground biomass yield (kg m^{-2}) of wheat to frequency of tillage, Arsi Negelle, Ethiopia.

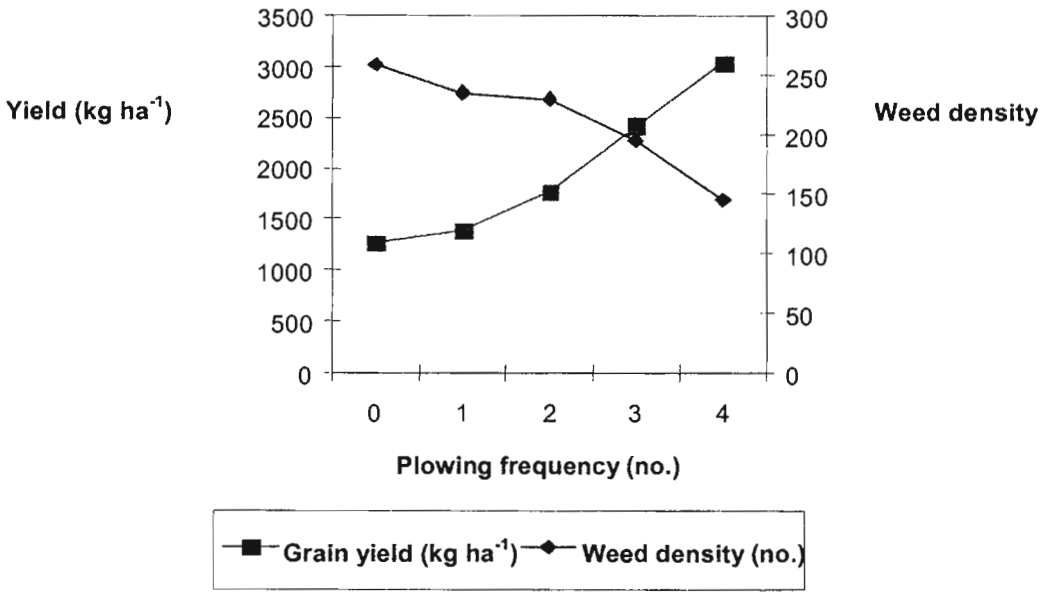

Fig. 3. Effect of tillage frequency on weed density and grain yield of wheat (1996-97), Arsi Negelle, Ethiopia.

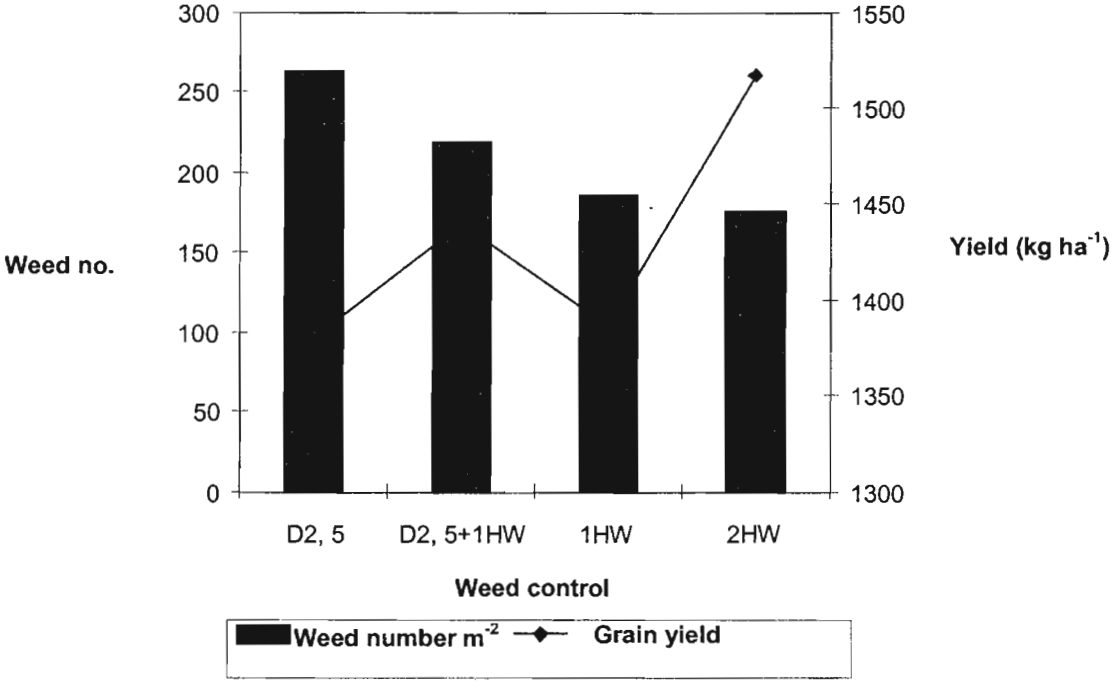

Fig. 4. Effect of weed control on weed density and grain yield of wheat, 1996-98, Arsi Negelle.

GLOBALIZATION OF THE WHEAT MARKET AND THE EMERGING TRENDS IN WHEAT RESEARCH AND TECHNOLOGY GENERATION

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ABSTRACT

The Green Revolution in wheat had a tremendous impact on food security in the developing world. The development of modern varieties, their free global exchange, and improved production practices were the cornerstones of wheat productivity growth, along with infrastructural investments and a conducive policy environment. The demand for wheat in 2020 is expected to be 40% greater than today's 552 million tons as per IFPRI's projections, but the resources available for wheat production are expected to be significantly lower, hence the challenge for increasing wheat supplies is as great today as it was three decades ago and the current sense of complacency is misplaced. Global food markets are increasingly becoming integrated, and the premium given in the past to food self-sufficiency is being replaced by an emphasis on economic competitiveness and comparative advantage. Agricultural resources devoted to cereal crop production are increasingly diverted to other agricultural and nonagricultural activities. Research systems, national as well as international, are facing declining budgets and uncertain futures. The free international movement of germplasm and information, which was an important factor in the success of the Green Revolution, is becoming increasingly restricted due to increasing quarantine restrictions and concerns of intellectual property protection. All of the factors discussed above lead to the central question examined in this paper: *What should the global wheat research system do in this changing world? The research system ought to focus on sustaining the competitiveness of wheat production in the developing world.* This can be achieved through a dramatic shift in the yield frontier, a constant drive to stabilize yields, and enhanced input use efficiency and responsiveness. The emphasis on profitability should not be restricted to the irrigated, favorable environments alone. Similar opportunities ought to be explored for marginal, rainfed environments. This paper highlights the role that wheat research and germplasm exchange can play in sustaining global wheat productivity growth over the next two decades. Technologies on the shelf and in the pipeline that will help meet the demand for wheat through 2020 are identified and evaluated.

FARMER PARTICIPATORY EVALUATION OF PROMISING BREAD WHEAT PRODUCTION TECHNOLOGIES IN NORTH-WESTERN ETHIOPIA

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ABSTRACT

Three promising bread wheat (*Triticum aestivum*) genotypes were compared with two released check varieties by farmers' research groups using both researcher and farmer-selected crop management practices. Agronomic and economic data and farmers' assessment criteria were collected during the conduct of the trials on four host farmers' fields during 1999. The statistical analysis across the four sites indicated that there were significant grain yield differences due to genotype and crop management level; however, interactions between genotype by site and genotype by management level were non-significant. Mean grain yields for the farmer- and researcher-managed plots were 1802 and 2148 kg/ha, respectively. One advanced line, HAR-2258, was high yielding and preferred by farmers on the basis of its crop stand, spike size, disease resistance, maturity class and crop uniformity. HAR-2258 and the check variety Abolla were both preferred by farmers for their quality in making staple food products. The improved crop management package for bread wheat was highly profitable for peasant farmers in N.W. Ethiopia: the researcher-managed production package increased wheat grain yields by an average of 19% across the four locations, and exhibited a marginal rate of return of 210% in comparison with the farmer-managed production practices.

INTRODUCTION

The highland of north-western Ethiopia (i.e., Gojam and Gonder zones) constitutes one of the important wheat (*Triticum* spp.) growing areas of the country (Aleligne and Regassa, 1992; Aleligne *et al.*, 1992), and is considered to have a high potential for the expansion of bread wheat production (Hailu, 1991). In fact, the production of wheat in N.W. Ethiopia has more than doubled over the past 17 years, due to the introduction of high yielding varieties (HYVs), policy reforms in 1990, a higher market price for wheat, and increased consumption of wheat by farm households (Alemu *et al.*, 1999).

In N.W. Ethiopia, wheat grain is used in the preparation of a range of products (Aleligne and Regassa, 1992): the traditional staple pancake ("injera"), bread ("dabo"), local beer ("tella"), local spirit ("areki"), and several other local food items (i.e., "kollo", "genfo" and "nifro"). In addition, wheat straw is frequently used in house construction, especially as a roof thatching material, and as feed for livestock. Wheat is the second most important cash crop after tef (*Eragrostis tef*) for peasant farmers in this area.

Historically, the farmers in N.W. Ethiopia produced a range of low yielding durum wheat (*T. durum*) landraces and an ancient bread wheat variety, "Israel" — known under several different local names (Alemu *et al.*, 1999). A number of improved bread wheat HYVs have been released by the national bread wheat research program over the last two decades, and these varieties dramatically increased the yield potential of wheat throughout Ethiopia (Amsal *et al.*, 1995). However, due to the rapid evolution of stripe rust (*Puccinia striiformis*) and stem rust (*P. graminis* f.sp. *tritici*) pathotypes, several of the most popular wheat varieties have been withdrawn from production (Bekele and Tanner, 1995). Therefore, particularly in Ethiopia, it is important that new wheat varieties be released frequently in order to minimize the risk of yield loss from the rust diseases; additionally, deployment of a range of varieties across the country will diversify resistance genes at the field level (Bekele and Tanner, 1995). A previous study revealed that the rate of varietal turnover for wheat in N.W. Ethiopia was 11 years (Alemu *et al.*, 1999) — a relatively slow rate of turnover in comparison to the global average of seven years.

The Ethiopian bread wheat HYVs respond dramatically to improved crop management practices (Amsal *et al.*, 1997, 1999). In particular, the profitability of wheat yield response to the application of N and P fertilizer for improved crop nutrition and 2,4-D for weed control has been verified under farmers' conditions across a range of soil types in N.W. Ethiopia (Asmare *et al.*, 1995; Minale *et al.*, 1999). However, some farmers still express reservations concerning the use of purchased crop inputs (Asmare *et al.*, 1995; Minale *et al.*, 1999).

To ensure that released varieties satisfy farmers' multiple and often complex objectives, it is important to actively involve farmers in the evaluation and selection process prior to varietal release (Heinrich, 1993). A farmer participatory approach to the evaluation of potential wheat production technologies should enhance the relevance of research by taking direct cognizance of farmers' conditions and needs, by choosing new technologies in cooperation with farmers, and by testing technologies under local conditions (Mutsaers *et al.*, 1997). During the past two decades, the national bread wheat research program of Ethiopia has made progress concerning the inclusion of farmers in the varietal release process. Beginning in the mid to late 1980s, on-farm verification of released varieties was conducted under both recommended and farmers' crop management practices on representative farmers' fields (Dereje *et al.*, 1990). Several years later, candidates for varietal release were tested using a similar trial design throughout the country (Asmare *et al.*, 1997). In each case, farmers were invited to assess both genotypic characteristics and the alternate crop production practices.

The current study involved the establishment of farmers' research groups at four sites in N.W. Ethiopia with the following objectives:

- to assess farmers' preferences for wheat genotypes and evaluation criteria, with a gender-sensitive perspective, extending from crop establishment to end use of harvested grain;
- to incorporate farmers' comments and reactions into the variety release process;
- to understand the implications of production technologies for roles and responsibilities within the farm household.

MATERIALS AND METHODS

Farmers' research groups (FRGs) were established in four localities across South Gonder and West Gojam zones in N.W. Ethiopia (viz., Geregera, Debre Mawi, Aba Aregay and Ata Seifatra) early in 1999 (i.e., at least two months prior to the normal commencement of wheat sowing).

Each FRG consisted of from 25-30 farmers, representing both male- and female-headed households, and a range of socio-economic characteristics and age groups. The FRGs met at agreed intervals with a multi-disciplinary team of research staff (i.e., a breeder, agronomist, economist, pathologist, and extension officer) from the Adet R.C. At these meetings, the members of the FRG shared their experiences with the research team, and were queried concerning characteristics desired in bread wheat varieties; questions for discussion were of the open-ended type.

Each of the four FRGs identified a member farmer with a representative field as a host for a wheat technology evaluation trial. The trial design consisted of three advanced bread wheat lines, viz., HAR-2469, HAR-1884 and HAR-2258, and two released varieties "Abolla" and "ET-13" as checks under two crop management levels. The three advanced bread wheat lines exhibited high yield potential and an adequate to high level of disease resistance in on-station trials during 1996-98; during 1999, all three lines were simultaneously included in the final year of the Regional Variety Trial (RVT) conducted at multiple station sites by staff of the Adet R.C.

The FRGs developed the levels of the component crop management practices comprising the farmer-managed (FM) package during their periodic meetings with research staff; however, research staff made a conscious effort not to influence the levels selected by the FRGs. Subsequent to the finalization of the FM packages by each FRG, the research staff informed the farmers of the levels to be included in the researcher-managed (RM) package. The components of each package are listed below:

Factor	Researcher-managed	Farmer-managed
Seed rate	175 kg/ha	150-200 kg/ha
Fertilizer - type	DAP and urea	DAP and urea
- rate	100 and 161 kg/ha, respectively	100 and 100 kg/ha, respectively
- application timing	all DAP at planting and N split (at planting and early tillering)	all DAP at planting and N split (at planting and early tillering)
Herbicide	2,4-D (1 l/ha at 25-30 DAE)	Not used
Weeding	One supplementary hand weeding	Two times hand weeding

The trial design used was an RCBD in split plot layout with two replications per site. The two crop management packages were assigned to main plots and the five wheat genotypes were assigned to sub-plots. The gross sub-plot size was 5 x 5 m (= 25 m^2).

Non-experimental factors such as time, method and frequency of land preparation, and time and method of sowing, seed covering, and harvesting were all implemented in accordance with the host farmers' customary practices and preferences.

The FRGs met at the trial sites several times during the growing season to evaluate the five genotypes and the management packages on the basis of the pre-harvest criteria identified previously during group meetings. Research staff collected detailed labor, agronomic and yield component data during the crop cycle. A net plot of 4 x 4 m (= 16 m^2) was harvested from each sub-plot by research staff to enable an accurate determination of grain yield.

Post-harvest assessment of the harvested wheat grain was conducted by three of the four FRGs (i.e., excluding the Ata Seifatra FRG). Each FRG identified several women, usually wives, from the group to grind the grain according to local practice, and then prepare two of the principal end-use dishes, injera and local bread, from the flour. The women were assigned the

responsibility to assess the quality of each wheat genotype from grinding up to the end of the baking process. Subsequently, the FRG met as a group to assess the palatability of each product. Numeric scores were used to record the qualitative data arising from the FRG assessments.

The agronomic data were analyzed separately for each site, and were also subjected to a combined analysis of variance across the four sites.

Economic analysis of the crop management packages was conducted in accordance with CIMMYT's partial budget methodology (CIMMYT, 1988). Nutrient prices used were 2.53 and 2.19 Ethiopian Birr (EB)/kg of DAP and urea, respectively. Daily wages were set at 3.50 EB/work-day. Grain was valued at 1.67 EB/kg for threshing and 1.72 EB/kg for planting. Labor estimates for the various operations were 0.4 work-days/ha for fertilizer application, 7.0 work-days/ha for herbicide application, 13 work-days/ha for hand weeding, and 20.0 work-days/ha for harvesting.

RESULTS AND DISCUSSION

Agronomic Analysis

Grain yield data obtained by the four individual FRGs are presented in Table 1. The grand mean grain yield across the four FRGs was 1975 kg/ha, while individual site means ranged from 1614 to 2434 kg/ha. At each site, the highest grain yield was obtained from the researcher-managed plots since the farmer-managed plots received a lower level of urea fertilizer and sub-optimal weed control. However, the Ata Seifatra FRG practiced more thorough hand weeding relative to the other FRGs; as a consequence, the grain yields obtained under both FM and RM were quite high and similar at this location. The lowest grain yields were obtained at the Aba Aregay site due to unreliable rainfall during the 1999 growing season.

The analysis of variance (ANOVA) of grain yields at individual sites (Table 2) indicated an absence of significant differences among the five genotypes tested, except at the Aba Aregay site ($P<0.1$). At this site, HAR-1884, HAR-2258 and ET-13 were equally high yielding and superior in performance to HAR-2469 and Abolla. Grain yield differences between the two crop management levels were significant at Geregera ($P<0.01$) and Debre Mawi ($P<0.1$): in both cases, RM plots outperformed FM plots. It should be emphasized that the low frequency of significant effects detected in the individual analyses can be partially attributed to the magnitude of the degrees of freedom for error for an individual ANOVA (i.e., $d.f._{error} = 9$).

The results of the combined ANOVA revealed that site, genotype, and crop management levels significantly affected wheat grain yield (Table 3). However, the interactions between site by genotype and genotype by crop management level were both non-significant, suggesting stable performance of the five tested genotypes (i.e., the five genotypes exhibited a relatively consistent yield ranking across the range of environments tested and all genotypes responded similarly to improved crop management practices). In contrast, multi-location on-farm verification trials conducted previously in Ethiopia revealed significance for these two interaction terms in different regions of Ethiopia (Dereje *et al.*, 1990; Asmare *et al.*, 1997).

Considering mean grain yields across the two management levels, HAR-2258 significantly outyielded all of the other genotypes except HAR-1884 (Table 3). Conversely, Abolla was lower yielding than all of the other genotypes except HAR-2469.

Mean grain yield under FM was 1802 kg/ha, ranging from 1344 kg/ha at Aba Aregay to 2421 kg/ha at Ata Seifatra. By contrast, the mean yield of wheat under RM was 2148 kg/ha, and ranged from 1859 kg/ha at Aba Aregay to 2448 kg/ha at Ata Seifatra. The smallest increment due to the improved management practices (i.e., 27 kg) occurred at Ata Seifatra. Expressed as a percentage of yield under FM, the grain yield responses to improved management ranged from 1 to 38% across the four FRGs; mean response was 19%.

Differences in plant height were observed among the five genotypes (Table 3), but there was no effect of crop management practices. ET-13 was significantly taller than all of the other genotypes, and Abolla was shorter than the others.

Economic Analysis of the Management Levels

Partial budget analysis was carried out for the two crop management levels, according to CIMMYT (1988) methodology (Table 4).

Using the standard prices for inputs and outputs as described in the Materials and Methods section, the marginal rate of return (MRR) for RM vis-a-vis FM was 210%, well in excess of the 100% level generally considered to be the minimum acceptable rate of return to motivate Ethiopian farmers to adopt a new technology (Asmare *et al.*, 1997; Amsal *et al.*, 1999).

In the current study, improved crop management increased wheat grain yields by an average of 19% across the four locations. The results of the partial budget analysis agreed with a previous report that improved crop management practices for bread wheat are profitable for farmers in N.W. Ethiopia (Asmare *et al.*, 1997).

Farmers' Assessments

Prior to sowing the trials, the members of the FRGs were asked to list all of the criteria that they consider important for an overall assessment of wheat genotypes. The FRG members then collectively narrowed down the list so that it finally included only the highest priority criteria. Subsequently, each FRG was asked to compare all of the criteria in a pair-wise fashion; a trait scored "1" for each pair-wise comparison in which it was considered to be of greater importance, and the sum was calculated for each trait (Table 5). Clearly, disease resistance was considered to be of paramount importance by all FRGs, reflecting the serious threat that rust diseases, in particular, present to wheat production in Ethiopia (Bekele and Tanner, 1995). However, there were apparent differences between the FRGs in South Gonder and West Gojam zones: for example, being situated in a higher altitude area, in general, the FRGs in South Gonder attached a high priority to "frost tolerance", while this criterion was not considered important in West Gojam. Furthermore, in West Gojam, injera quality and market demand ranked in the top five criteria, suggesting that farmers in West Gojam may be more market-oriented vs. subsistence-oriented than their counterparts in South Gonder.

Farmers' assessments of the five wheat genotypes were elicited both pre- and post-harvest. In the pre-harvest assessment, yield potential and disease resistance were reported by most

farmers in both zones as important pre-harvest criteria determining their varietal preferences. Farmers considered seedling emergence and vigor, tillering ability and spike size as indicators of grain yield potential (Table 6). Although grain yield was the primary concern of most farmers, a sizable minority stated their preference for taller varieties to provide the raw material for roof thatching and to be more capable of suppressing in-crop weeds. Seed size and seed filling were considered important factors by some farmers.

When the FRGs viewed the genotypes during the soft/hard-dough stage of grain filling, spike length, spike density, low levels of disease on leaves and spikes, maturity class and crop uniformity were the main selection criteria considered. Farmers reiterated their concerns regarding wheat susceptibility to disease; specifically, they characterize as "dangerous" any disease that attacks the spike or the peduncle, causing a failure of grain filling. Farmers appreciated ET-13 for its high level of resistance to all foliar diseases, but were disappointed with its relatively small and short spikes (Table 6).

Regarding crop maturity, farmers expressed a preference for genotypes in the intermediate maturity class. For example, HAR-1884 was earlier than the other genotypes (Table 6); farmers appreciated its plant architecture, but worried about pre-harvest sprouting in a year of extended rainfall. Early crops are also subject to a greater degree of damage by foraging birds. Farmers cited a local proverb [in Amharic]: "Mejemeria yetenagerewun sew yitelawal, tolo yederesewun wef yibelawal" — which translates to "the first speaker or witness is hated, the early crop is eaten by birds". In contrast, genotypes in the late maturity class are disliked because of the risk of terminal drought stress and a greater risk of frost damage (i.e., in the high altitude areas).

Concerning weed management, the members of the FRGs voiced a preference for hand weeding vs. the use of 2,4-D, expressing concerns that 2,4-D exhibited some side effects on crop leaves (i.e., causing a transient yellowing) and did not effectively control all weeds in their fields. Hand weeding was considered most suitable for the wheat crop by the majority of the farmers, because it removed all types of weeds; hoeing after hand weeding improved crop vegetative performance, according to the FRGs. However, within the FRGs, some farmers favored the use of 2,4-D because of the resultant savings in weeding labor.

Seed characteristics, particularly seed color, and end-use quality, particularly for making bread and injera, were considered by most farmers to be important post-harvest criteria. Seed color also had price implications in local markets with white wheat grain receiving a premium. The women identified by each FRG to process the harvested grain into bread and injera rated the five genotypes on their relative quality in terms of ease of grinding, the flour volume produced per unit of grain, the water absorption ability of the flour, and elasticity and extensibility of the dough (Table 7). Bread and injera quality was also assessed for each wheat genotype; farmers ranked the bread and injera based on "eye" size, and product color and elasticity (Tables 7 and 8). Summarizing all of the component factors, HAR-2258 and Abolla were the most highly rated genotypes for bread and injera quality (Table 8).

CONCLUSIONS

The test line HAR-2258 was significantly higher yielding than all of the other bread wheat genotypes included in the trial except for HAR-1884 — which was disliked by farmers due to its early maturity. Furthermore, HAR-2258 received a favorable evaluation by the members of the

FRGs for most pre- and post-harvest evaluation criteria, including its quality for the production of bread and injera. Thus, HAR-2258 should be given a high priority for release for the peasant farm communities of N.W. Ethiopia. The results of the current study will be forwarded to the national wheat variety release committee for their consideration. This study also verified the profitability of the recommended wheat crop management production package under farmers' circumstances in N.W. Ethiopia.

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Table 1. Mean grain yield (kg/ha) of five bread wheat genotypes under researcher and farmer crop management levels at four sites in north-western Ethiopia.

	Site								Mean	
	Geregera		Debre Mawi		Aba Aregay		Ata Seifatra			
Genotype	**RM**	**FM**	**RM**	**FM**	**RM**	**FM**	**RM**	**FM**	**RM**	**FM**
HAR-2469	2056	1592	2399	1671	1287	1148	2294	2447	2009	1714
HAR-1884	2264	1754	2057	1874	2264	1377	2117	2795	2176	1950
HAR-2258	2703	1671	2100	2063	1927	1706	2627	2488	2339	1982
Abolla	1856	1326	1917	1658	1559	1023	2423	1953	1939	1490
ET-13	2125	1613	2081	1867	2259	1466	2648	2558	2278	1876
Mean	2201	1591	2111	1827	1859	1344	2448	2421	2148	1802
C.V.(%)	13.4		13.1		13.7		18.5		15.6	

RM: Researcher-managed; FM: Farmer-managed.

Table 2. Effects of genotype and crop management level on wheat grain yield (kg/ha) at four sites in north-western Ethiopia.

	Site			
	Geregera	**Debre Mawi**	**Aba Aregay**	**Ata Seifatra**
Genotype	NS	NS	P=0.057	NS
HAR-2469	1824	2035	1218	2327
HAR-1884	2009	1966	1820	2456
HAR-2258	2187	2082	1816	2557
Abolla	1591	1787	1290	2188
ET-13	1869	1974	1862	2601
Management	P<0.01	P=0.051	NS	NS
RM	2201	2111	1859	2448
FM	1591	1827	1344	2421
Interaction	NS	NS	NS	NS
Mean	1896	1969	1614	2434

NS: non-significant.

RM: Researcher-managed; FM: Farmer-managed.

Table 3. Effects of genotype and crop management level on wheat grain yield (kg/ha) and plant height (cm) from the combined analysis.

	Grain yield	Plant height
Site	**	NS
Genotype (G)	**	***
HAR-2469	1862 BC	79 C
HAR-1884	2063 AB	84 B
HAR-2258	2161 A	81 BC
Abolla	1714 C	75 D
ET-13	2077 AB	98 A
$LSD_{(0.05)}$	219	3.8
Management (M)	*	NS
High	2148 A	85
Low	1802 B	82
$LSD_{(0.05)}$	271	NS
Interaction (G x M)	NS	NS

*, **, *** Significant at the 5, 1 and 0.01% levels, respectively.
NS: non-significant.
Means within a column followed by the same letter are not significantly different at the 5% level of the LSD test.
RM: Researcher-managed; FM: Farmer-managed.

Table 4. Partial budget analysis for the two crop management levels across four sites in north-western Ethiopia.

	Researcher managed	Farmer managed
Mean yield (kg/ha)	2148	1802
Adjusted yield (kg/ha)[a]	1933	1622
Gross field benefit (birr/ha)	3228	2710
Fertilizer cost (birr/ha)[b]	609	475
Seed cost (birr/ha)	301	301
Labor cost (birr/ha)[c]	194	161
Total costs that vary (birr/ha)	1104	937
Net benefit (birr/ha)	2124	1773
Marginal cost (birr/ha)	167	
Marginal net benefit (birr/ha)	351	
Marginal rate of return (%)	210	

[a]Yield was adjusted downwards by 10% to more accurately reflect yields obtained under farmers' harvesting and threshing.
[b]Nutrients plus cost of application.
[c]Includes cost of chemicals for weed control, application labor, hand weeding labor, and harvesting labor.

Table 5. Ranking of the criteria established by farmers' research groups for the evaluation of bread wheat genotypes in two zones of north-western Ethiopia.

South Gonder			West Gojam	
Criterion	**Score**		**Criterion**	**Score**
Disease resistance	14		Disease resistance	12
Frost tolerance	13		Injera quality	11
Flour yield ("Bereket")	12		Market demand	10
Maturity (earliness)	11		Yield	8
Yield	10		Flour yield ("Bereket")	8
Lodging resistance	9		Bread quality	8
Tillering ability	7		Seed color	5
Spike size	6		Maturity (earliness)	5
Seedling vigor	5		Tillering ability	4
Injera quality	5		Seed size	4
Market demand	5		Spike size	2
Bread quality	4		Plant height	1
Seed size	3		Seedling vigor	0
Plant height	1			
Seed color	0			

Table 6. Farmers' subjective evaluation of specific field characteristics of five wheat genotypes.

Characteristic	Genotype				
	HAR-2469	**HAR-2258**	**HAR-1884**	**Abolla**	**ET-13**
Emergence	3	2	3	3	2
Seedling vigor	3	3	3	2	2
Tillering ability	2	3	2	2	2
Plant height	1	1	2	1	3
Disease resistance	2	2	1	2	3
Maturity	2	3	1	2	3
Spike size	3	3	2	2	1
Frost tolerance	2	2	2	2	3

1 = undesirable (i.e., slow, low, short, susceptible, early, small).
2 = intermediate (i.e., medium or moderate).
3 = desirable (i.e., fast, high, tall, resistant, late, large).

Table 7. Farmers' subjective evaluation of the attributes related to making injera and bread from the five tested wheat genotypes.

Attribute	Location	Genotype				
		HAR-2469	HAR-1884	HAR-2258	Abolla	ET-13
Ease of grinding grain	Geregera	Hard	Very hard	Very hard	Soft	Medium
	Debre Mawi	Medium	Hard	Hard	Soft	Soft
	Aba Aregay	Medium	Hard	Very hard	Medium	Soft
Flour volume ("Bereket")	Geregera	Medium	High	High	Medium	High
	Debre Mawi	High	High	High	High	High
	Aba Aregay	Medium	High	High	High	High
Water absorption ability	Geregera	High	High	High	Very high	High
	Debre Mawi	Medium	Low	Medium	High	Low
	Aba Aregay	Medium	Medium	Medium	High	Medium
Elasticity of dough	Geregera	High	Very high	High	High	High
	Debre Mawi	High	Medium	Low	High	Medium
	Aba Aregay	Medium	Low	Low	Medium	Low
Extensibility of leavened mixture	Geregera	High	High	High	High	High
	Debre Mawi	Low	High	Medium	High	Medium
	Aba Aregay	Low	Medium	Medium	Low	High
Bread (overall ranking)	Geregera	3	1	4	2	5
	Debre Mawi	2	3	4	1	5
	Aba Aregay	4	5	2	1	3
Injera (overall ranking)	Geregera	3	2	5	1	4
	Debre Mawi	3	2	1	4	5
	Aba Aregay	5	3	1	2	4

1 = best quality for bread or injera; 5 = lowest quality for bread or injera.

Table 8. Ranking[a] of the farmers' subjective evaluation of the injera and bread making quality of the five tested wheat genotypes.

Genotype	Bread quality	Injera quality
HAR-2469	3	3
HAR-1884	5	4
HAR-2258	2	1
Abolla	1	2
ET-13	4	5

[a] Ranking based on "eye" size, and product color and elasticity.
1 = best quality for bread or injera; 5 = lowest quality for bread or injera.

A CLIENT ORIENTED RESEARCH APPROACH TO THE TRANSFER OF IMPROVED DURUM WHEAT PRODUCTION TECHNOLOGY

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ABSTRACT

To have an impact on agricultural production, productivity and farmers' welfare, it is of vital importance to forge effective links between the institutions and relevant actors involved in the process including farmers. Cognizant of this fact, the Debre Zeit Agricultural Research Center (DZARC) financed by the Cool Season Food and Forage Legumes Project and the Joint Vertisol Project (JVP) established a total of seven Farmer Research Groups (FRGs) in two woredas of Eastern Shoa Zone during the 1999 cropping season. Of these, the wheat variety FRG in the selected watershed area of Gimbichu woreda is discussed. The objectives of this study were to form client-oriented alliances with farmers in the process of wheat variety development and transfer. Twenty-three members of the wheat variety FRG residing in the area were involved. Each farmer planted an improved durum wheat variety called 'Kilinto' and their local variety side by side using a ridge and furrow (RF) seed bed. The mean grain yield obtained by farmers from the improved variety was 2330 kg/ha cf. the local variety at 1930 kg/ha. The marginal rate of return of the improved variety was found to be 1627%, which is economically profitable.

INTRODUCTION

Agricultural technology generation, development and transfer process as a system has different actors (researchers, farmers, extension workers, etc.) playing key roles in maintaining its holistic nature. The contribution of each of the actors will have a great impact on agricultural production, productivity and on farmers' welfare. To reach this goal, forging effective links between the institutions and relevant individual actors involved in the process including farmers is of vital importance.

Cognizant of this fact, the DZARC, financed by the Cool Season Food and Forage Legumes Project and the Joint Vertisol Project (JVP) established a total of seven Farmer Research Groups (FRGs) in two woredas of Eastern Shoa Zone during the 1999/2000 cropping season. The aim of establishing FRGs is to form strong alliances with farmers in the process of agricultural technology generation, development and transfer more demand driven and hence client oriented.

A series of meetings was held with farmers during the course of forming FRGs. In the discussions held, farmers were allowed to enumerate their production constraints and elaborate upon them and group them accordingly based entirely on their willingness. The major production constraints identified by farmers were:

- A foliar disease, rust, that affects all aerial parts and destroys lentil,
- Lack of high yielding varieties of chickpea,
- Lack of improved and high yielding varieties of wheat,
- Water logging problem in wheat production,
- Rate of fertilizer application in wheat,
- Weed problem in wheat, and
- Lack of fuel wood and feed shortage.

Following the identification of these constraints, farmers were allowed to group themselves in one or more of these problem areas and the FRGs were named after the problems. Planning and review meetings with farmers were held where farmers decided on the type of experiment that they would like to undertake. The treatments in the experiments were also selected together with farmers and the role of researchers and extension workers in this regard was more as a moderator. Researchers were drawn from different disciplines ranging from breeders, agronomists, soil scientists and foresters to agricultural economists and research-extension professionals. Wheat FRG is one of the FRGs established with an aim to evaluate improved durum wheat technology on farmers' fields at Cheffe Donsa.

Wheat is one of the major cereal crops grown in the central highlands of Ethiopia, ranking fifth in production and fourth in yield (Hailu *et al.*, 1992). Two wheat species are dominantly grown in the country. These are bread wheat (*Triticum aestivum*) and durum wheat (*T. turgidum* var *durum).* Durum wheat is traditionally grown on the heavy black soils (Vertisols) of the highlands at altitudes ranging between 1800-2800m, exclusively under rainfed agriculture (Tesfaye and Getachew, 1991). The country is recognized as a center of genetic diversity for durum wheat. The Ethiopian farmers have been growing this crop for millennia. During recent past, durum wheat used to occupy more than 60% of the total wheat area in Ethiopia (Hailu *et al.*, 1991; Tesfaye and Getachew, 1991). Currently both bread and durum wheat occupies equal areas although bread wheat is on the increase.

Chefe Donsa is one of the highland waterlogged Vertisol areas (2450 m a.s.l.) where durum wheat planting accounts for about 51 percent of total cereal production. However, yields of farmers' cultivars are low. Use of an adapted and high yielding variety is one of the important factors for yield increment. Thus, this experiment was initiated together with farmers to give them the opportunity to evaluate improved technologies of durum wheat for further adoption of the technology.

MATERIALS AND METHODS

Twenty-three members of the FRG residing in a selected watershed area of Gimbichu woreda were planted with an improved durum wheat variety called Kilinto and farmers local variety side by side using RF seedbed on the same plot size for the sake of comparison. The improved wheat variety was planted at the recommended rate and in the recommended time (i.e., seeds were broadcast at the rate of 150 kg/ha and fertilizer was applied at the rate of 150/50 kg/ha N/P_2O_5). Each variety was planted on a field size of 50x50 m^2 of land. Economic analysis was carried out according to CIMMYT methodology (CIMMYT, 1988).

RESULTS AND DISCUSSION

The grain yields on the fields of the twenty-three participant farmers ranged between 1400 to 3328 kg per hectare for improved wheat variety, and 800 to 3000 kg/ha for local wheat variety. The mean grain yields obtained by farmers who grew the improved packages were 2329 kg/ha while farmers who grew the local variety obtained a mean grain yield of 1930 kg/ha. It was also observed that the straw yields of the improved variety Kilinto outyielded that of the local variety (Table 1).

The economic analysis revealed that the total variable cost of the local package was 675.27 Birr/ha while that of the improved wheat package was 723.33 Birr/ha for improved production package (Table 1). The marginal analysis also showed that the improved varieties had considerably higher marginal rate of return relative to the local variety package. Hence, the improved variety contributed greater amount of net benefits as compared to the local variety. The marginal rate of return of the improved variety was found to be 1627%, which is economically profitable and feasible (Table 2).

In conclusion, the agronomic and economic analyses clearly indicated the superior performance of the improved variety as compared to the local variety. The results obtained from wheat varietal FRG revealed that the improved varieties outyielded the local variety. Members of the wheat FRG expressed their interest in growing durum wheat variety Kilinto. Farmers' criterion of selecting Kilinto includes high yielding, desirable seed color, threshability and straw palatability. As a result, many farmers expressed a tremendous demand for the improved varieties.

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Questions and Answers:

Vicki Tolmay: What is the wheat straw used for in Ethiopia?

Answer: It is generally used as animal feed. In some areas, it is used as a thatching material.

Table 1. Partial budget of the improved and local durum wheat varieties, 1999/2000.

Particulars	Variety	
	Kilinto	Local
Average grain yield (kg/ha)	2329.70	1930
Average straw yield (kg/ha)	3482.04	2880
Gross field benefits of		
Grain (Birr/ha)	3960.49	3281
Straw (Birr/ha)	870.51	720
Total gross field benefits (Birr/ha)	4831	4001
Cost of fertilizer (Birr/ha)	359.90	401.71
Cost to apply fertilizer (Birr/ha)	3.43	3.56
Cost of seed (Birr/ha)	360	270
Total costs that vary (Birr/ha)	723.33	675.27
Net benefits (Birr/ha)	4107.67	3325.73

Table 2. Marginal analysis of the improved and local durum wheat varieties, 1999/2000.

Treatments	Costs that vary (Birr/ha)	Marginal cost (Birr/ha)	Net benefits (Birr/ha)	Marginal net benefit (Birr/ha)	Marginal rate of return (%)
Local	675.27		3325.73		
Kilinto	723.33	48.06	4107.67	781.94	1627

ECONOMICS OF FERTILIZER USE ON DURUM WHEAT

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ABSTRACT

Farmers in wheat growing areas of Ethiopia rely on wheat production for various purposes. Even though the role played by fertilizer use is increasing, economic use of fertilizer is not well addressed due to a wide range of factors. Economic use of fertilizer consists of among other things, choosing the right kind and quantity of fertilizer including both input and output prices. The relation between fertilizer and wheat price determines the level of profitability in the use of fertilizer and thereby effective demand for fertilizer by farmers. The multiple regression analysis is used to derive the mathematical wheat yield function for different application of nitrogen and phosphorous fertilizers. In the two nutrient case, profit maximization requires the value of marginal physical productivity of each nutrient be equal to its respective marginal nutrient cost times the investment cost. The economic optimum point is a dynamic concept, which is influenced by variation in relative price of input-output. This issue can be analyzed using sensitivity analysis. At the prevailing grain and nutrient prices, the study revealed that, using optimum rate of nutrients would give a 65% marginal rate of return over the traditional farmers' rate. As the ultimate success of fertilization of wheat depends on the prices of wheat and fertilizers, developing a fertilizer pricing policy that is based on cost-benefit analysis should be a prerequisite. Thus both policy makers and farmers should pay attention to the type and economic optimum use for fertilizer efficiency in durum wheat production.

INTRODUCTION

Wheat is one of the most important cereal crops largely grown by peasants in most parts of the country. Farmers in wheat growing areas of the country rely on wheat production for local consumption and a source of income.

Ethiopia is the largest producer of wheat in sub-Saharan Africa. Currently wheat occupies about 0.882 million ha of land (CSA, 1996). The national mean wheat grain yield is low mainly due to suboptimal management practices. A substantial gap has been observed between yields on research stations and farmers' fields primarily due to inefficient transfer of technology and the lack of necessary inputs for wheat production (Bekele *et al.*, 1994). This is the main reason why many people recommend that the best solution to the low agricultural productivity is to improve the system of farming practices and provide information to farmers on improved farm technology. Provision of fertilizers along with sufficient knowledge and information about fertilizer application is among the important factors for improving agricultural productivity.

Even though the role-played by fertilizer use in increasing crop yield is well perceived, economic

use of fertilizer is not well considered due to a wide range of factors. According to Workneh (1989), farmers in Ethiopia apply fertilizer at a rate less than the rate commonly advised by some extension agents, as farmers are not convinced of the economic return from the recommended rate. Deresse (1985) also identified lack of location specific recommendation about fertilizer application rate as a major constraint on fertilizer use by peasants of Ethiopia. The economic use of fertilizers consists of among other things, choosing the right kind and the right rate of fertilizer and applying it in the right place at the right time including consideration of prices of input and output. In addition lack of profitability in the use of fertilizer is assumed to be determined by the unfavorable relation between fertilizer and crop price, which results in low effective demand for fertilizer by farmers. Nevertheless, to justify the effect of such crop and fertilizer price relationship on profitability by empirical studies, it is important to analyze the use of fertilizer focusing on efficiency and profitability.

OBJECTIVES OF THE STUDY

In line with this, the specific objectives of the study include:

1) To derive wheat response function to the application of nitrogen and phosphorous fertilizer
2) To determine an optimum combination of fertilizers that can reduce the cost of fertilizer use thereby generating profitable returns
3) To assess the effect of price change on the economic optimum levels of fertilizer use
4) To estimate the gap between farmers' actual use of fertilizer and the optimum fertilizer level and identifying its impact on returns

MATERIALS AND METHODS

This study employs production function of multiple regression analysis to determine economic rate of nitrogen and phosphorous fertilizers that maximize profit. The production function in economics describes the technical or physical relationship between output and one or more variable inputs (Ellis, 1988). Production function analysis is the most important of all the techniques used in production economics due to its simplicity and its power to provide extra information regarding production and growth and also economic development and planning (Singh, 1986). It provides not only information about the technical maximum level of output that can be achieved in the application of a certain variable input, but also gives insight into the determination of productivity of that input. The marginal productivity is defined as the amount of output obtained from a unit increase in the variable input. It is a highly useful concept to measure the degree of economic efficiency in allocation of resources between alternative choices. A production function may be expressed in several forms one of which being an algebraic equation. The quantity of a physical output is determined by the quantity of factor inputs.

Thus, it can be said that quantity Y depends on factor inputs $X_1, X_2, X_3, \ldots, X_n$, and can be written in functional form as:

$$Y = f(X_1, X_2, X_3, \ldots\ldots, X_n)$$

Where Y is the amount of yield of a given agricultural commodity, the Xs are the inputs required to produce the agricultural commodity, and f is the fitted functional form relating output to the

n variable inputs.

Given the technical possibilities set by a production function, it can be assumed that the degree of economic efficiency in resource allocation between alternative enterprises can be measured on the basis of the marginalist principle of expanding factor input use, up to the level where marginal cost equals marginal revenue (Koutsoyiannis, 1979). The economic optimum or the equilibrium level of input in a production function can be altered by changes in prices or by technical change in production, since such changes would increase or decrease the marginal product of the variable input.

The Data

The pooled results of nitrogen and phosphorous (N-P) response study data which were conducted in Ada and Akaki areas in the central highlands of Ethiopia are the main source of data for this analysis. Field trials on uptake and response of durum wheat at different rates of nitrogen and phosphorous fertilizer were conducted by the soil section of the Debre Zeit Agricultural Research Center. The study area is one of the main agricultural regions of the central highlands of Ethiopia where the soils are Vertisols, which are regarded as marginal for durum wheat production. In addition to this, the actual farmers' practices of fertilizer application on wheat are taken from the demonstration trials conducted by the department of Agricultural Economics of the Debre Zeit Agricultural Research Center.

Model Specification

The mathematical relation between wheat yield and various levels of nitrogen and phosphorous fertilizer are statistically fitted to the experimental data. Because of its mathematical simplicity and its ability to facilitate a more detailed technical and economic analysis, the quadratic multiple regression function is used to estimate the mathematical relationship of yield and different fertilizer rates. In addition, the quadratic functional form has been widely used because it is easily generalized to models with more than one nutrient. It allows for easy interpretation of interaction effects of explanatory and dependent variables. It also gives an accurate picture of crop response at least up to the fertilizer levels well above those, which could be advised to use (Jauregui and Sain, 1992).

The quadratic relationship being the econometrics yield function, adapted as an appropriate function for this analysis is of the following form:

Where:

$$Y_w = b_0 + b_1N + b_2P + b_{11}N^2 + b_{22}P^2 + b_{12}NP + U$$

Y_w = the physical quantity of wheat yield in kg/ha
b_0 through b_{12} are regression coefficients defining the response to input levels
N = the level of nitrogen input applied in kg/ha
P = the level of phosphorus input applied in kg/ha
U = disturbance term assumed to be of zero mean and variance

All regression variables are estimated by the methods of least squares using the statistical software program SPSS/PC Version 6. After deriving the regression variables, the profit function

can be derived using response function and crop and fertilizer prices. In the two nutrient cases, profit to be maximized is expanded to incorporate the definitions of the response function, f(N,P). The deduction of total costs that vary, $(P_nN + P_pP)$ (1+R) from the gross field benefits, P_w f(N,P), attained from a unit of land provide a profit function. In this case the profit function (Π) to be maximized is given as:

$$\Pi = P_w f(N^*, P^*) - (P_n N^* + P_p P^*)(1 + R)$$

Maximization of this profit function yields the following optimality condition:

$$P_w f_n = P_n(1+R) \qquad \text{and} \qquad P_w f_p = P_p(1+R)$$

That is, profit maximization requires that the value of marginal physical productivity of each nutrient be equal to its respective marginal factor cost (nutrient price) times the investment cost (1+R). This means that the last unit of money invested in each nutrient must yield the same amount of money weighted by the investment cost, (1+R).

The minimum rate of return acceptable to farmers (R) reflects the cost of money invested, i.e., the benefit given up by the farmer by tying up the working capital in the farm for a period of time. For a technology that represents an adjustment in current farmers practice (such as different fertilizer rates for farmers that are already using fertilizer), the time and effort spent in learning is lower. Hence, a lower minimum rate of return acceptable to farmers (50-100%) can be estimated (CIMMYT, 1988).

Thus the optimal level of nutrient can be derived from the profit maximization function using the system of simultaneous equation. It is indicated that, at the point of profit maximization

$$f_n - P_n(1+R) / P_w = 0 \qquad \text{and} \qquad f_p - P_p(1+R) / P_w = 0$$

Substituting f_n and f_p by the marginal physical productivity of each nutrient obtained from the response function and r_n and r_p by the respective price ratio gives the following equilibrium equation:

$$b_1 + 2b_{11}N + b_{12}P - r_n = 0$$
$$b_2 + 2b_{22}P + b_{12}N - r_p = 0$$

Solving these two equations with respect to N and P yield the derivation of the optimal level of nutrients:

$$N^* = [2b_{22}(r_n - b_1) - b_{12}(r_p - b_2)] / [4b_{11}b_{22} - b^2_{12}]$$
$$P^* = [r_p - b_2 - b_{12}N^*] / [2b_{22}]$$

Where:

P_w = Wheat price (Birr/kg)
P_n = N price (Birr/kg)
P_p = P price (Birr/kg)
$r_p = P_p(1+R) / P_w$ (price ratio of P to wheat)
$r_n = P_n(1+R) / P_w$ (price ratio of N to wheat)
R = Minimum rate of return
f_n = Marginal Physical Product of N
f_p = Marginal Physical Product of P

EMPIRICAL RESULTS

Regression Analysis

As already stated, the explanatory variable inputs used in this analysis are nitrogen and phosphorous. Twenty-five observations on yield of wheat are obtained from different combinations of the two fertilizers. Estimation of the structural parameters, standard errors, coefficient of determination (R^2) and t-statistic are provided for the average over locations.

$$Y_w = 1546.89 + 9.91N^* + 1.88P - 0.039N^{2**} - 0.079P^2 + 0.024NP, \; R^2 = 0.794$$

*, ** Indicate statistical significance at 1% and 10% probability levels, respectively.

Where: Y_w = Wheat yield (kg)
N = Amount of nitrogen nutrient (kg); and
P = Amount of phosphorous nutrient (kg).

Based on the results of the standard error, the explanatory variable nitrogen and its interaction with phosphorous, 'NP' does in fact influence yields of wheat. The coefficient of determination (R^2) is high, which shows that wheat yields are well explained by nutrients.

Economic Optimum

The necessary condition for the attainment of the most profitable or the economic optimum level of nutrients is the equality between the value of marginal physical product of each nutrients to its price times by the investment cost, (1+R). Marginal physical products of nitrogen (MPP_n) and phosphorous (MPP_p) nutrients can be predicted from the partial derivatives of the regression equation.

The determination of the economic optimum level of nutrient is based on the price per kg of Birr 1.98 for wheat, Birr 4.00 for nitrogen and Birr 2.71 for phosphorous and a minimum rate of return acceptable to farmers (R) is assumed to be 50%. Based on the grain and nutrient price combination, the price ratios (r_n and r_p) for wheat are calculated using $r_n = P_n (1+50\%)/ P_w$ and $r_p = P_p (1+50\%)/ P_w$. After deriving the price ratio, the economic optimum level of nitrogen and phosphorous (N* and P*) for wheat production can be formulated.

Given the above price ratios, optimum combinations of the two nutrients that maximize profit are found to be 92.20 kg N/ha and 12.64 kg P/ha. Substituting these values of nitrogen and phosphorous into the regression equation, the predicted yield is found to be 2169 kg/ha. Total return less fertilizer cost is thus Birr 3690.04/ha.

The determination of the economic optimum level of nutrients under a range of price situations used to illustrate the sensitivity of the profit maximizing combinations of nutrients and net returns to the change in relative prices. The economic optimum level of nitrogen and phosphorous at different nutrient and wheat price and the yield expected at such level of nutrients are provided in Table 1. The table illustrates the cost of fertilizer incurred and the net return earned. Two price level of N and P when the product price remains at constant and conversely two price level of wheat keeping the price of nutrients at constant are used for this purpose. At a constant grain price, the increase of nutrient price will decrease the net benefit for two reasons. On the one hand due to a high nutrient price the total amount of nutrients per unit area will be

smaller. Consequently the yield expected and the gross benefit earned are declining. On the other hand, for the higher nutrient prices, the higher the cost of the nutrients, the lower net returns will farmers to earn.

Any change in relative prices alters the economic optimum level of nutrients. The unfavorable price relationship that is a fall in grain prices in relation to the nutrient prices and/or a rise in nutrient prices in relation to grain prices results the economic optimum level occurring at a lower level of inputs and outputs. It can be observed that there is variation in the economic level of nutrients and net returns from the use of fertilizer from time to time when factor and product prices vary. Pertaining to this case, experience in Ethiopia shows that fertilizer price has an increasing trend. Under such situation, farmers will be reluctant to apply higher amount of nutrients. As a result of this, net benefits that farmers generate are declining.

For a constant price of wheat Birr 1.98/kg, an increase of nitrogen price by 0.89 Birr and phosphorous by 0.57 Birr is the reason for the sacrifice of net benefit of Birr 126.96/ha. Out of such decline of net benefit, 67% is due to out put effect while the remaining 33% is due to cost effect. That is, the increase of nutrient prices has a disincentive effect for the farmers to use more amounts of nutrients and also increase the cost of fertilizer. On the other hand, keeping the price of nitrogen at Birr 4.00/kg and phosphorous at Birr 2.71/kg, increasing the price of wheat by 0.30 Birr make the farmers to enjoy an incremental net benefit of Birr 665.01/ha. The discussions so far try to point out the optimum level of nutrients that maximize profit under the various relative prices. Actually the amount of profit maximizing level of nutrient under the current factor and product prices are much higher than the rate that farmers would apply to their plot. Demonstration trials conducted in the study area showed that on the average farmers would apply 39.20 kg nitrogen and 10.03 kg phosphorous per hectare for wheat.

Table 2 focuses on the differences between the effect of the optimum fertilizer rate determined and the actual farmers' fertilizer rate. The idea is thus to ask what changes can be made in the present farmers' practice and to compare the change in net benefit with the change in fertilizer rate, costs and yields.

Comparison between the two alternatives can be made using the method of marginal analysis. The marginal rate of return indicates what farmers can expect to gain, on the average, in return for their investment when they decide to change from the method of lower rate of fertilizer application to the optimum fertilizer combinations. Farmers gain expectation from using a new practice is compared to the minimum rate of return acceptable to farmers. For a farmer who already use fertilizer, 50% is estimated as the minimum rate of return as the farmer adjust the current fertilizer application rate into optimum fertilizer level.

In light of this, by adopting the optimum level of nutrients, wheat producer farmers incur an extra investment of Birr 328.61/ha. In return, by hanging their practice they will obtain extra benefit of Birr 211.93. Thus, using optimum rate of nutrients would give a 65% marginal rate of return. The result of the marginal rate of return obtained from using optimum fertilizer rate is greater than the minimum rate of return that farmers expect to gain. This shows the fact that adjusting the current fertilizer rate into the optimal and higher level of fertilizer rate is profitable for wheat production.

CONCLUSIONS AND IMPLICATIONS

It is evidenced that nitrogen and phosphorous fertilizer as a whole has been profitable input to the production of wheat. Although this is a general trend which needs further investigation to evaluate the relevant kind and optimum level of fertilizer, the finding of this study suggest that cultivated wheat on Vertisols require higher amount of nitrogen than phosphorous.

In terms of value productivity it has been shown that farmers are discouraged to the use of fertilizer in wheat production as a means of assuring stable increase of their income due to relatively higher cost of fertilizer relative to lower price of grain. Such unfavorable relationship of factor and product price affects the expected level of input and out put. Consequently, the success of increasing wheat production from the use of fertilizer depends on the ability of the producer to buy the nutrient at favorable price and sell grain when prices are high.

As the ultimate success of fertilization of wheat depends on the prices of wheat and fertilizers, developing a fertilizer pricing policy that is based on cost benefit analysis thus assists the farmers to increase fertilizer use. In this regard reducing excessive marketing costs through the involvement of more private sectors might be possible to make the use of fertilizer cost-effective. In addition, efficient distribution of fertilizer can be accomplished through farmers education, infrastructural development and agricultural programs concerned with fertilizer use and distribution.

Peasant farmers in Ethiopia may not be able to purchase fertilizer because of lack of capital even if they are aware of the use of fertilizer. On top of this, the amount of fertilizer required to maximize profit is higher than what the farmers actually use on their wheat crops. Thus, in order to provide farmers the necessary capital and increase the amount of fertilizer use, efficient credit delivery mechanism has to be designed. Thus, policy makers, researchers and farmers should pay attention to the principle of fertilizer economics in durum wheat production.

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Questions and Answers:

D.G. Tanner (Comment): The current study is based on the response of durum wheat to fertilizer on flat waterlogged Vertisols. With improved drainage, such as the BBF system, N and P response would increase markedly as well as grain yield – up to 6 t/ha.

Wolfgang Pfeiffer: Since the N response of the genotypes used in your study will affect the results, there must be a substantial difference between dwarf modern and tall landrace genotypes. Have these differences in response pattern been considered?

Answer: No, the study considered a tall variety only (Boohai variety). I feel that there should be a variety specific study on fertilizer response.

Table 1. Economic optimum levels of N and P with the corresponding wheat yield, cost of nutrients and net returns.

P_n (Birr/kg)	P_p (Birr/kg)	P_w (Birr/kg)	N* (kg/ha)	P* (kg/ha)	Yield (kg/ha)	Gross Field Benefit (Birr/ha)	Costs that Vary (Birr/ha)	Net Benefit (Birr/ha)
4.00	2.71	1.98	92.20	12.64	2169	4294.62	604.58	3690.04
4.89	3.28	1.98	82.29	8.70	2126	4209.48	646.40	3563.08
4.00	2.71	2.28	98.11	15.54	2190	5006.88	651.83	4355.05
4.89	3.28	2.28	89.40	11.81	2158	4920.24	713.85	4206.39

Table 2. Comparison between optimum and farmers' fertilizer practice.

Item	Farmers' fertilizer practice	Optimum fertilizer practice
Fertilizer rate (kg/ha)		
- Nitrogen	39.20	92.20
- Phosphorous	10.03	12.64
Predicted grain yield (kg/ha)	1896.00	2169.00
Cost of nutrients(Birr/ha)	275.97	604.58
Net Benefit (Birr/ha)	3478.51	3690.04
Increment relative to farmers' practice		
- Grain yield (kg/ha)	273.00	
- Cost of nutrients (Birr/ha)	328.61	
- Net Benefit (Birr/ha)	211.93	
Marginal Rate of Return (%)	65	

ON-FARM ANALYSIS OF DURUM WHEAT PRODUCTION TECHNOLOGIES IN CENTRAL ETHIOPIA

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ABSTRACT

On-farm analysis of three newly released durum wheat varieties (Foka, Kilinto and Quami) and two check wheat varieties (Boohai and ET-13) under two alternate management packages (an improved practice comprising 100 kg/ha DAP, 100 kg/ha urea and a seed rate of 150 kg/ha vs. farmers' practice comprising 100 kg/ha DAP, 50 kg/ha urea and a 130 kg/ha seed rate) was conducted at Alemtena, Shenkora, Minjar and Tullubollo areas in central Ethiopia for two years. The results indicate that there was no significant difference among the varieties for grain and straw yield across locations. However, the difference between the management practices was significant in most trials. The improved practice gave a grain yield advantage of 16, 18 and 19% at Alemtena, Shenkora and Tullubollo, respectively, and a straw yield advantage of 13.6% at Shenkora and 14.9% at Tullubollo over farmers' practice. The improved practice also provided a marginal rate of return of 168% at Alemtena, 332% at Tullubollo, and 365% at Shenkora cf. the farmers' practice. Farmers rating indicated that the new varieties are better than the checks in terms of grain quality for making certain local dishes, straw quality for feed, disease resistance and weed competition. Given these merits and the goal of increasing varietal diversity, demonstration and large-scale dissemination of the three new varieties and the improved management practice are recommended. However, to ensure wider adoption of these technologies, the promotion of strong horizontal linkages between the local wheat processing industries and the farming sector is advisable.

INTRODUCTION

Wheat is a staple food crop for most households in rural and urban areas in Ethiopia. However, wheat yield is low and unstable due to several technical and socio-economic constraints. Weed competition, low or declining soil fertility, diseases, particularly rust, in appropriate use of agronomic practices such as seeding rate, sub-optimal fertilizer application and herbicide use are some of the major technical constraints (DZARC, 1989; Hailu and Chilot, 1992; Workneh and Mwangi, 1993). Limited supply of seeds of improved varieties, high prices and unavailability of augmenting technologies like fertilizer and herbicides in required quantity and at required time, and inadequate cash or credit for purchase of inputs are the major socio-economic constraints.

The short life span of improved varieties in production is also another constraint to increased and sustainable wheat production. It was estimated that the mean number of years a new variety stays in production is low - about four years - and ranges from 2.5 to 4 years (Regassa *et al.*, 1998), beyond which the yield starts to decline, or their disease resistance breaks down.

Therefore, for wheat production to be sustainable, varieties should be replaced frequently and continuously, and management practices must also be developed and fine-tuned continuously. As an effort to develop new varieties to replace already released varieties or to increase diversity, three new durum wheat varieties (Foka, Kilinto, Quami) have been recently developed and released by research scientists in the Wheat Improvement Program. Improved agronomic practices (seeding rate of 150 kg/ha and blanket fertilizer recommendation of 100 kg DAP and urea) were also recommended. But these technologies, varieties and agronomic recommendations, need to be fine-tuned further under farmers' conditions. Therefore, evaluation of these technologies was conducted under farmers' condition in some areas in the central part of the country. This paper presents the results of agronomic and economic analysis of the performance of these varieties and the improved agronomic practice and the results of farmers' assessments of the varieties from different criteria.

MATERIALS AND METHODS

On farm evaluation was conducted at Tullubollo, Minjar and Shenkora locations in the central highlands and at Alemtena in the rift valley area of the country for two consecutive years (1997/98 and 1998/99). Alemtena is a drought-prone area as it is in the rift valley and a red light soil is a dominant type. At Tullubollo and Shenkora, the heavy black Vertisol is dominant. The soils in Minjar are light black soil as termed by the farmers. The improved varieties were evaluated along with two other already released varieties (Boohai and ET-13), which served as standard check, under improved and farmers' management practices. The improved practices, as already stated, were a seed rate of 150 kg/ha and fertilizer rate of 100 kg/ha of DAP and 100 kg/ha of urea, while the farmers' practices were seed rate of 130 kg/ha and fertilizer rate of 100 kg/ha of DAP and 50 kg/ha of urea, which are average of the farmers' current practices. All other practices such as methods, timing and frequency of plowing, weeding and harvesting, were left to farmers' decision and practices. The trial was arranged in split plot design, management being on the main plot while varieties were on sub-plots, with two replications per site. The main plot size was 10 m x 10 m while the sub-plot size was 5m x 5m. Data were then collected on grain and straw yield and subjected to analysis of variance for agronomic analysis. For economic feasibility evaluation, input and output prices were collected and both partial budgeting and marginal rate of return analyses were conducted according to the CIMMYT (1988) methodology for treatments with significant agronomic response. Farmers' evaluation of the varieties was also elicited and a variety index was constructed for each criterion following Maxwell *et al.* (1995).

RESULTS AND DISCUSSION

The effect of variety on grain yield was not significant at all locations (Table 2). This can also be seen from the very marginal grain yield difference among varieties at both management practices (Table 1). This result agrees with the previous results from on station experiment including Boohai, Kilinto, and Foka at Alemtena (DZARC, 1996) which showed no significant yield difference. A cluster analysis at Debre Zeit, Akaki, Chefe Donsa, Alemtena, Enewary, Sinana and Ambo locations (DZARC, 1997) also indicate that Boohai, Foka and Kilinto varieties fell into the same cluster group. These results are expected as all of them are reported to have adaptation both to drought prone and highland areas (DZARC, 1996). The practice main effect was found to be significant at all locations except at Minjar, but its effect was more pronounced ($p \leq 0.01$) at Tullobollo and Alemtena than at Shenkora ($p \leq 0.05$) (Table 2). The improved practice gave a grain yield advantage of 16, 18 and 19% at Shenkora, Alemtena and Tullubollo, respectively. The results at Tullubollo and Shenkora agree with the

blanket fertilizer recommendation of 100 DAP and 100 urea (50 kg top dressing) on heavy black soils with waterlogged problem (DZARC, 1996). This result also supports the previous findings from on farm experiment on response of Boohai variety to fertilizer under recommended seeding rate at Akaki, Ada and Gimbichu which revealed the highest grain yield at the improved practice (Workneh and Mwangi, 1992). The significant effect of practice at Alemtena may be partly due to the effect of fertilizer on plant growth and development. As it is an area characterized with less moisture stress, increased fertilizer rate may promote fast and early plant growth and development thereby significantly increase grain yield. This was also reported by farmers who hosted the on farm evaluation. The non-significant effect of practice at Minjar could be attributed to the natural high fertility of the soil. This agrees with the farmers' explanation that high fertilizer application on light textured soils induces plant lodging. The year effect was highly significant at all locations except at Minjar, which may be due to significant difference in the amount and distribution of rainfall between the two years at all locations except Minjar. However, the interaction effect of variety by year was less pronounced at Minjar and non-significant at all other locations, indicating lesser tendency or the non-existence of a tendency to change in ranking of varieties with year. Other interaction effects on grain yield were non-significant except practice by variety ($P \leq 0.10$) at Minjar and Alemtena and practice by year ($P \leq 0.10$) at Alemtena.

The effects of variety, practice and their interaction on straw yield were not significant at all locations except practice effect at Shenkora and Tullubollo (Table 3). The year effect for straw yield was significant at all locations, maybe for similar reasons as for grain yield. The insignificant effect of variety on straw yield may also be for similar reason as for grain yield. At Tullubollo and Shenkora, higher and significant straw yield was obtained from improved practice. It gave a straw yield advantage of 13.6% at Shenkora and 14.9% at Tullubollo over the farmers' practice. Miressa *et al.* (1991) from on-station experiment reported that increasing nitrogen application on Vertisols under the recommended seeding rate results in highly significant increase in straw yield of durum wheat. This is ascribed to the low total nitrogen and organic matter content of Vertisols (Miressa *et al.*, 1991).

As significant agronomic response was observed for practice effect only, economic analysis was conducted for practice effect alone. Its result indicates that both practices provided positive net benefit at all locations. Higher net benefit was, however, obtained from the improved practice, which agrees with the agronomic results. The improved practice also provided a marginal rate of return greater than the minimum acceptable rate of 100% (CIMMYT, 1988) at all locations (Table 4).

Results of farmers' assessments of the varieties evaluated were given in Table 5. It indicates that the new varieties are better than Boohai in weed resistance, shattering resistance and straw palatability for animal feed. But they were rated to have lodging problem except Kilinto and ET-13 compared to Boohai. All the new varieties have either comparable (Quami) or better ease of harvesting and bundling (Kilinto and Foka) than Boohai variety. ET-13 was rated the best for ease of threshing. Except Foka, the other new varieties were rated to have better ease of threshing than Boohai. All of the new varieties except Kilinto were rated better than Boohai in water logging resistance while ET-13 was rated the most susceptible one. In terms of bread quality, all of the new varieties were rated closely with Boohai except ET-13. ET-13 was also rated not suitable for kinche, while Quami was rated better than Boohai, when others were rated inferior. In terms of quality of roasted grains, all varieties were rated to be better than Boohai. Except Quami, all were rated to be better in injera quality than Boohai. For disease resistance, the new varieties were rated either equal

(Kilinto) or better than Boohai (Quami and Foka), while ET-13 was rated to be the least resistant. Maturity wise, Quami and Foka were rated to be late maturing followed by Boohai. ET-13 and Kilinto were rated to be equally early maturing ones.

CONCLUSIONS

This study revealed that there was no significant grain and straw yield differences between the new and check varieties. However, with respect to disease resistance, Boohai variety was reported to be susceptible to leaf rust disease (DZARC, 1996). This indicated that the new varieties are better than Boohai in their disease reaction and thus there is a need to replace Boohai with these resistant varieties. Farmers also rated the new varieties better in terms of disease resistance, grain quality for some local dishes, and straw quality for feed. Given these merits of the new varieties, demonstration and dissemination of the new varieties is commendable. Given the disease resistance, farmers' priority is, however, yield or income maximization, and other criteria are somewhat secondary as there are alternative means of coping with some of them. Farmers indicated that the new varieties are not better than the currently widely grown bread wheat varieties like Kubsa and Pavon. This difference is explained by the tetraploid nature of durum wheat, whose yield as a result is generally lower than bread wheat, which is a hexaploid. Although farmers expect that the new varieties will fetch the same price as other durum wheat varieties, which is often greater than the price paid for bread wheat in the domestic markets, this price advantage of the durum wheat varieties is, however, not sufficient to surpass the yield advantage of bread wheat. Therefore, to ensure wider adoption of these varieties or durum wheat technologies in general, policies that improve the price margin for durum wheat need to be in order. One means is promoting strong horizontal linkage between the local processing industries and the farming sector. Until recently, this linkage is either non-existent or very weak, as most processing industries depend for their raw material need on imports from abroad. There is lack of awareness by the local processing industries about the quality standard and for some even the availability of durum wheat in the domestic market. Thus, awareness creation through research product fairs for processing industries will play an essential role leading to increased demand in the local market.

The study also revealed that with improved practice the new varieties provided a grain and straw yield advantage and were economically more feasible cf. the local practice. As a result, demonstration of the improved practice is also commendable. However, as the results at Minjar and other locations further indicate the possible agronomic and economic feasibility of reduced and additional nitrogen, respectively, beyond the given experimental range, a further fine tuning study both on station and on farm to determine the optimum nitrogen fertilizer application is suggested.

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Questions and Answers:

Hugo van Niekerk: What are the major reasons for the high seed rate? Is this not an economic consideration?

Answer: Agronomic practices are primary reasons. Seed is broadcast by hand, sometimes with a poor seedbed, and the eventual number of plants is much less than is normal when using tractor driven equipment. High seed rate is also the first line of defense against weeds. Also, the seed rate for durum is higher than for bread wheat.

Miriam Kinyua: The difference in seed rate used in Ethiopia and South Africa is very high – 150 kg/ha vs. 25-50 kg/ha, respectively. Why this big difference?

Answer: Land preparation and method of planting play a great role in determining the optimal seed rate. SA farmers prepare land well and use seeders. Ethiopian farmers use animal drawn implements.

Table 1. Grain and straw yield (kg/ha) of wheat varieties evaluated with improved and local practices.

Location	Practice	Grain yield					Straw yield				
		Foka	Kilinto	Quami	ET-13	Boohai	Foka	Kilinto	Quami	ET-13	Boohai
Shenkora	Improved	2227	2391	2287	2655	2140	3691	3475	4145	4447	3743
	Local	1857	1939	1818	2578	1718	3423	3276	3281	3838	3348
Minjar	Improved	2327	2048	2079	2102	2199	3697	3713	4333	4022	3763
	Local	2137	1974	2315	2079	1639	4099	3563	3984	3877	3735
Alemtena	Improved	1392	1774	1569	1729	1680	2901	3543	3255	3795	3219
	Local	1464	1294	1255	1408	1572	3323	3112	2738	3491	3202
TulluBollo	Improved	2190	2176	2170	2166	2107	3281	3444	3708	3719	3578
	Local	1814	1773	1930	1660	1895	3094	2955	3133	3347	2904
Mean	Improved	2049	2094	2035	2136	2038	3357	3531	3819	3929	3567
	Local	1815	1739	1847	1850	1737	3423	3178	3259	3578	3229

Table 2. Results of analysis of variance for wheat grain yield at the four locations.

Source of variation	d.f.	Location							
		Shenkora		Minjar		Alemtenna		Tulubolo	
		Mean Square	F-value	Mean Square	F-value	Mean Square	F-value	Mean Square	F-value
Main effects									
→ Practice	1	2390079	4.88**	298004	1.67	1061397	11.38**	44948075	12.37**
→ Variety	4	741056	1.51	268567	1.50	135193	1.45	53264	0.15
→ Year	1	9795689	19.98**	494	0.003	4871908	52.24**	34239141	94.24**
2-way interaction									
→ Practice x Variety	4	36982	0.08	336618	1.88†	184310	1.98†	102941	0.28
→ Practice x Year	1	513172	1.05	62758	0.35	507246	5.44*	357426	0.98
→ Variety x Year	4	167450	0.34	351077	1.96†	70430	0.76	106354	0.29
3-way interaction									
→ Practice x Variety x Year	4	71506	0.15	68591	0.38	62702	0.67	45833	0.13

† F-test significant at $P < 0.10$ level; * F-test significant at $P < 0.05$ level; ** F-test significant at $P < 0.01$ level.

Table 3. Results of analysis of variance for wheat straw yield at the four locations.

Source of variation	d.f.	Location							
		Shenkora		Minjar		Alemtenna		Tulubolo	
		Mean Square	F-value	Mean Square	F-value	Mean Square	F-value	Mean Square	F-value
Main effects									
→ Practice	1	3359854	3.05†	58717	0.06	575493	1.03	7388875	14.9**
→ Variety	4	1063703	0.97	633844	0.64	979556	1.76	655624	1.31
→ Year	1	5814463	5.28*	1955360	19.8**	16072314	28.89**	20533349	41.1**
2-way interaction									
→ Practice x Variety	4	227640	.21	313801	0.32	580758	1.04	248854	0.5
→ Practice x Year	1	454656	0.35	40081	0.04	110277	0.2	228278	0.46
→ Variety x Year	4	3869992	0.41	156792	0.16	421253	0.76	385691	0.77
3-way interaction									
→ Practice x Variety x Year	4	163820	0.15	641089	0.65	566310	1.02	169460	0.34

† F-test significant at $P < 0.10$ level; * F-test significant at $P < 0.05$ level; ** F-test significant at $P < 0.01$ level.

Table 4. Net benefits and marginal rates of return for the two management practices at three locations.

Location	Practice	Total Costs that Vary	Net Benefit	Marginal Cost	Marginal Net Benefit	Marginal Rate of Return (%)
Tullubollo	Local	540.35	256.85			
	Improved	670.69	3000.70	130.34	432.85	332
Alemtena	Local	522.71	2219.91			
	Improved	651.26	2435.30	128.55	215.39	168
Shenkora	Local	560.42	3069.44			
	Improved	696.92	3567.25	136.50	497.81	365

Table 5. Results of farmers' assessment of varieties.

	Variety index for characteristics				
Characteristic	**ET-13**	**Kilinto**	**Quami**	**Foka**	**Boohai**
Weed resistance	67	86	96	93	87
Less shattering	53	93	93	87	80
Straw palatability for feed	76	76	80	68	68
Lodging resistance	92	88	57	68	70
Ease of harvesting and bundling	70	100	90	100	90
Ease of threshing	80	52	68	45	50
Water logging resistance	33	67	100	80	73
Bread quality	55	76	75	65	80
Kinche quality	-	80	100	80	93
Injera quality	80	80	30	86	50
Taste roasted	90	92	76	87	75
Disease resistance	70	90	100	100	90
Early maturity	80	80	60	57	65

Variety index is computed as per Maxwell *et al.* (1995):

$$= \Sigma \frac{\text{(Number of responses for each rank x corresponding weight of rank)}}{\text{Total number of responses x highest weight}} \times 100$$

A STUDY OF THE ADOPTION OF BREAD WHEAT PRODUCTION TECHNOLOGIES IN ARSI ZONE

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ABSTRACT

Tremendous efforts have been exerted towards the development and dissemination of improved bread wheat (*Triticum aestivum*) production technologies in Arsi Zone of Ethiopia since the inception of comprehensive integrated package projects in the late 1960s. The current study examined the rate of adoption of wheat production technology and identified factors influencing the adoption of those technologies. A total of 300 farm households were surveyed in the five major wheat growing areas of Arsi Zone during May 1999. About 95% of the sampled farmers had grown wheat during the 1998 cropping season. The sampled farmers produced a total of 13 different wheat varieties during 1998. Survey results revealed that 91.5% of the farmers adopted improved bread wheat varieties: Kubsa (39% of growers) and Pavon (25% of growers) were the two most widely adopted varieties in the region. In terms of the total wheat area, the six dominant varieties covered 92.5% of the wheat area, while semi-dwarf bread wheat varieties occupied 88.5% of the total wheat area. About 73% of wheat growers planted a single variety of wheat. DAP and urea fertilizers were adopted by 92 and 26% of the wheat growers, respectively. More than half of the fertilizer adopters (57.6%) applied DAP on wheat fields at a rate between 76 and 100 kg/ha. The level of urea application was quite low: 17.5 kg/ha was the mean urea application rate for the sampled wheat growers. About 32% of the urea adopters practiced top dressing of urea. Only about 15% of the wheat growers adopted the current blanket fertilizer recommendation (100 kg DAP and 100 kg urea per ha) on wheat fields. While the majority of the wheat growers (84%) practiced hand weeding, about 63% adopted chemical weed control and frequently at suboptimal rates: wheat growers, on average, applied 0.46 l of 2,4-D herbicide per ha of wheat. Finally, logistic regression analyses revealed that institutional factors, principally access to credit, extension contacts, and farmer education level, significantly influenced the adoption of bread wheat production technologies.

INTRODUCTION

Wheat is one of the major cereal crops in Ethiopia both in terms of area and total production. Over the period 1992-95, annual wheat production was 0.783 million t of wheat produced on

0.693 million ha of land, revealing a low mean national yield of 1.2 t/ha (CSA, 1995b), and accounting for 14% and 13% of total cereal production and cultivated area, respectively. The apparent low productivity can be attributed to several factors (Tanner *et al.*, 1993) including: limited adoption of high-yielding varieties, fertilizer and other modern inputs, slow progress in developing wheat cultivars with durable resistance to diseases, and depleted soil fertility.

The existing low levels of wheat production and productivity cannot meet the growing demand for food due to a rapidly increasing population in conjunction with changing consumption patterns. As a result, the level of wheat self-sufficiency at the national level in Ethiopia is estimated at only 55%, necessitating importation to fill the gap (Tanner and Mwangi, 1992). A significant improvement in wheat production can be realized by raising yields per unit area through the intensive application of improved wheat production technologies. Such intensification should encourage the correct utilization of existing technologies and/or the adoption of new ones.

Arsi Zone hosted a long-term comprehensive integrated rural development project (i.e., CADU/ARDU) beginning in 1967. Since that time, additional agricultural research and development activities have been implemented in the region, benefiting local farmers through the dissemination of improved agricultural technologies. Different adoption studies have been conducted in Arsi Zone to assess the level of and factors influencing technology adoption (Aregay, 1980; Mulugetta, 1995). One limitation of adoption studies is that the results relate to a specific base year whereas constraints and opportunities are dynamic and vary from year to year. Generating the latest information, therefore, will keep stakeholder groups aware of the acceptance and performance of the existing and/or new research outputs on farmers' fields. This study was conducted in Arsi Zone with the main objective of examining the socio-economic factors that influence the adoption of selected wheat production technologies. The specific objectives of the study were:

1. to assess and quantify the extent of adoption of improved bread wheat production technologies; and
2. to identify factors influencing the adoption of improved bread wheat production technologies.

MATERIALS AND METHODS

The Study Area

The five surveyed woredas are located in Arsi Zone in south-eastern Ethiopia, with elevations ranging from 1980 to 3760 m a.s.l. Arsi Zone is characterized by a cereal-dominated farming system in which bread wheat and barley are the major crops. In the 1994/95 cropping season, cereals accounted for 80% of the total cultivated land in the region (CSA, 1995a): according to the same survey, wheat (28%) and barley (22%) comprised 50% of the total cropped area.

Sampling Method and Data Analysis

The survey was conducted in the five major wheat-producing woredas of Arsi Zone: Asasa, Bekoji, Etheya, Lole, and Robe. Within each of the five woredas, Peasant Associations (PAs) which had been intensively served by technology dissemination agents for many years were selected, while farmers were randomly selected from within the selected PAs. A sample of 60 farmers was taken from each woreda; thus, a total sample comprising 300 small-holder

farmers was surveyed during May 1999. Data were collected using a structured questionnaire.

Survey data were collected on farm household characteristics, farm resources, farming practices, and the adoption of wheat varieties, fertilizer and herbicide.

Descriptive statistics (i.e., means and ratios) were used to describe the characteristics of the farming households and the rates of technology adoption. A multivariate logistic regression model was used to identify factors influencing the adoption of selected bread wheat production technologies (i.e., improved varieties, fertilizer and herbicide). The logistic model is expressed in terms of the natural log of the odds ratio (i.e., the ratio of the probability that the farmer will adopt a given technology (P) to the probability he will not adopt (1-P)), which is called logit:

$$\ln [P/(1-P)] = \beta_o + \beta_1 X_1 + \ldots \beta_k X_k$$

where β_i is the estimated coefficient associated with variable X_i for k independent variables included in the regression. The logistic regression coefficients are estimated using the maximum likelihood method. In the current study, the dependent variable in each model is the decision of the farmer whether or not to adopt improved bread wheat production technologies (i.e., improved varieties, fertilizer, and herbicide). It was hypothesized that the adoption of bread wheat production technologies is influenced by multiple socio-economic and institutional factors in the study area.

RESULTS AND DISCUSSION

Socio-economic Characteristics

The mean age of the surveyed household heads was 46.9 years with an average family size of 6.9 persons (Table 1). Nearly 54% of the farmers were illiterate; 17.1% and 7.5% had completed primary and secondary school education, respectively. The remaining 21.5% of the farmers possessed basic literacy skills. Seventeen per cent of the surveyed households were headed by females (Table 1).

Land holdings in the study area are relatively small with a mean farm size of 10.70 timad (2.7 ha) varying from 7.48 timad (1.9 ha) in Etheya woreda to 14.27 timad (3.60 ha) in Bekoji (Table 2). The areas allocated for grazing and fallowing are very limited. For farmers reporting such land use, the mean area of grazing land was 0.78 ha while the mean area of fallow was 0.66 ha; however, only 58 and 36% of the surveyed farmers reported allocating land for grazing and fallow, respectively. Thus, across Arsi Zone, land allocated for grazing and fallow represented 17.0% and 8.9% of the total owned land, respectively. The problem of land scarcity was particularly apparent in Etheya and Robe woredas where there is a pronounced deficit of grazing land and where fallowing is virtually non-existent. To partially alleviate the land shortage problem, 22% and 21% of the farmers rented-in land for crop production and grazing purposes, respectively. Share cropping arrangements are also common in the study area (Table 2). A minority of the farmers shared or rented-out land, usually due to a shortage of either draught power (i.e., oxen) or inputs (i.e., seed and fertilizers).

The mean number of livestock kept on the farm ranged from 4.9 TLU in Etheya to 9.75 TLU in Asasa (Table 2). The relatively low livestock population in Etheya can perhaps be attributed to the land shortage constraint in the area. On average, an individual household owned 2.13 oxen.

Adoption of Bread Wheat Production Technologies

Improved varieties

Of the total sample of 300 farmers in Arsi Zone, 95% planted wheat during the 1998 cropping season (Table 3).

The characteristics of the known bread wheat varieties produced in Arsi Zone during 1998 are listed in the following table:

Variety	Date of release	Current status
Israel	?	under production
Enkoy	1974	obsolete
K6290-Bulk	1977	under production
K6295-4A	1980	under production
ET-13	1981	under production
Pavon-76	1982	under production
Batu	1984	obsolete
Dashen	1984	obsolete
Mitike (HAR1709)	1993	under production
Wabe (HAR710)	1994	under production
Kubsa (HAR1685)	1994	under production
Galama (HAR604)	1995	under production

The varieties Dashen and Batu became obsolete due to a new stripe rust (*Puccinia striiformis*) pathotype which resulted in a severe stripe rust epidemic in Ethiopia during 1988-89 (Bekele and Tanner, 1995). The variety Enkoy became obsolete as a result of a new stem rust (*P. graminis* f.sp. *tritici*) pathotype which resulted in a severe stem rust epidemic in Ethiopia during 1993-94 (Bekele and Tanner, 1995). The variety Israel was never officially released, and there is no information concerning its introduction to Ethiopia (Amsal *et al.*, 1995) - probably more than 100 years ago (i.e., before there was an agricultural research program). It continues to be produced by peasant farmers throughout Arsi Zone for some preferred quality aspects - particularly its large, white seed - despite exhibiting low yield potential and a range of disease susceptibilities.

Only 8.5% of the wheat growers in Arsi used local unimproved wheat varieties (i.e., "Local" and "Israel") in 1998 (Table 3). Kubsa (HAR1685) was the most widely-adopted wheat variety in the region: 39% of wheat producers grew Kubsa in 1998. Farmers also reported high adoption rates for other improved wheat varieties, i.e., Pavon-76 (25%), Wabe (15%), and ET-13 (11%). In terms of the total wheat area sown to each variety, Kubsa (34.5%) and Pavon-76 (26%) accounted for 60.5% of the total wheat area sown in 1998; four other varieties, viz. Wabe, Dashen, Batu and ET-13, covered 11.5%, 7.6%, 7.3% and 5.6% of the wheat area, respectively (calculated from Tables 3 and 4). Thus, the six most frequently grown wheat varieties occupied 92.5% of the total wheat area sown in Arsi during 1998. Of

these six dominant varieties, five are semi-dwarfs (i.e., only ET-13 is a tall improved variety); thus during 1998 in Arsi Zone, semi-dwarf bread wheat varieties (i.e., Kubsa, Pavon, Wabe, Dashen, Batu and Galama) occupied 88.5% of the total wheat area. Only 5.1% of the total wheat area in 1998 was sown to local varieties. Variation was observed in the distribution of varieties across the woredas, reflecting both adaptation to specific locations and area-specific farmer preferences (Table 3); however, Kubsa was dominant in three of the five woredas. The survey results also revealed that adopters of each variety grew a mean area of 4 timad of Kubsa, 4.8 timad of Pavon, 3.5 timad of Batu, and 3.3 timad of Dashen (Table 4).

The predominance of semi-dwarf varieties of bread wheat in Arsi Zone is directly attributable to the heavy investment in wheat breeding by the CADU/ARDU project and the national wheat research program of Ethiopia. The grain yield potential of bread wheat cultivars released in Arsi Zone over the period from 1949 to 1987 has increased at the rate of 2.2% or 77 kg/ha per annum (Amsal *et al.*, 1995). Furthermore, the recently-released semi-dwarf varieties Kubsa and Galama significantly outyielded the taller check varieties Enkoy and ET-13 in a series of on-farm trails conducted throughout Ethiopia during the mid 1990s (Asmare *et al.* 1997).

Pavon (19.2 qt/ha) was reported as the highest yielding wheat variety in Arsi (Table 4) followed by Dashen (17.0 qt/ha), Batu (16.8 qt/ha), and Kubsa (16.8 qt/ha). The other widely adopted variety in the region, Wabe, exhibited a yield of 15.4 qt/ha. ET-13 and Israel yielded the lowest (i.e., below 10 qt/ha). Variations in yield were observed across the different woredas. The highest yields were reported in the Etheya and Lole woredas which are known to possess favorable conditions for wheat production. Robe (water-logged), Asasa (drought-stressed) and Bekoji (low P status of soils) exhibited relatively low mean wheat yields.

Of the thirteen wheat varieties reported in Arsi during 1998 (Table 3), 77% and 62% were reported in Bekoji and Asasa woredas, respectively. Farmers in Etheya and Robe woredas reported production of only 46% of the total number of wheat varieties. The number of varieties reported in Lole was only four (i.e., 31%). About 72.8% of the wheat growers in Arsi planted only one variety, while 24.4% produced two wheat varieties, and 2.8% grew three varieties during 1998 (Table 5).

Concerning the 13 varieties grown during 1998 by surveyed farmers, it was of interest to note that two "obsolete" varieties, viz., Dashen and Batu, comprised 14.8% of the total wheat area in Arsi. Dashen, a varietal release in 1984, achieved outstanding grain yields throughout Ethiopia, and was significantly higher yielding than any of the wheat cultivars released previously by the national wheat research program (Bekele and Tanner, 1995). However, during the 1988 cropping season, significant yield losses due to an epidemic caused by a new race of stripe rust were recorded on state and peasant farms producing Dashen; Dashen and varieties such as Batu, possessing a common stripe rust resistance gene, were immediately dropped from seed multiplication and dissemination programs (Bekele and Tanner, 1995), but they apparently retained popularity among peasant farmers as evidenced by the current survey. One contributing factor could be that stripe rust is much less severe on susceptible cultivars produced under low levels of fertilizer application (Tanner *et al.*, 1993) as commonly occurs on peasant farms.

In contrast to the case of Dashen and Batu, the level of production of the variety Enkoy

during 1998 demonstrated the almost total demise of a previously popular bread wheat variety: Enkoy occupied only 0.5% of the surveyed wheat area in Arsi during 1998. Enkoy had been extremely popular with wheat farmers throughout Ethiopia as a result of its properties of competitiveness with weeds, high levels of resistance to the major diseases of wheat in Ethiopia, and wide adaptability across the many agro-ecological zones of the country (Bekele and Tanner, 1995). Particularly after the demise of Dashen in 1988, the production of Enkoy expanded to cover an estimated 70% of the national bread wheat area; however, by 1993, stem rust levels up to 100S were reported in farmers' fields throughout major wheat producing zones in south-eastern Ethiopia, and some farmers reported total crop failure as a result (Bekele and Tanner, 1995). Thus, by the 1998 cropping season, farmers in Arsi had essentially replaced Enkoy with newer varieties such as Kubsa and Wabe or with seed of older varieties such as Pavon-76 and ET-13 which continue to exhibit satisfactory yields and adequate levels of disease resistance.

Fertilizer

In Ethiopia, given the stated national objective of attaining food self-sufficiency, there have been considerable efforts expended in recent years to promote the adoption of chemical fertilizers in small-holder agriculture. In particular, Arsi Zone has benefited from agricultural technology development and dissemination activities since the inception of the first comprehensive package projects during the late 1960s.

The survey results revealed that 92.3% of the wheat growers in Arsi Zone applied DAP on wheat during 1998 (Table 6). A DAP adopter in Arsi applied an average of 90.3 kg of DAP per ha on wheat while the weighted mean (i.e., including non-adopters of DAP) was 83.3 kg of DAP per ha of wheat in Arsi. In terms of mean DAP application rates on wheat for adopters, the five woredas are ranked in order as follows: Etheya (107.7 kg per ha), Lole (98.7), Bekoji (93.1), Asasa (79.2), and Robe (70.0).

The survey results also revealed that only 26% of the wheat growers in Arsi applied urea to wheat in 1998 (Table 6). The highest adoption rate for urea application was observed in Etheya (61.4%), followed by Robe (23%) and Asasa (22.4%) woredas. Although the mean rate of urea application by urea adopters was 67.2 kg/ha on wheat, the weighted mean rate of urea application on wheat in Arsi was only 17.5 kg/ha.

The survey results also revealed that only about 15% of the farmers adopted the current MoA blanket fertilizer recommendation for wheat (i.e., 100 kg DAP and 100 kg urea per ha).

The method of fertilizer application varied between DAP and urea (Table 7). Virtually all farmers in the region applied DAP correctly as a basal application at the time of sowing. About 68% of the farmers applying urea applied all at planting while 32% practiced top dressing of urea. Experimental results in central Ethiopia revealed that split application of the urea N source, with 1/3 applied at planting and 2/3 top dressed at the mid tillering stage of the crop, was agronomically beneficial under water-logged soil conditions (Tilahun *et al.*, 1996). Split application of N enhanced grain yield, grain N content and uptake, and apparent N recovery and agronomic efficiency. It is worth noting that, in the current study, the highest incidence of top-dressing of urea was reported in the Robe and Bekoji woredas; these two woredas exhibit the highest rainfall amounts and incidence of water-logging among the five surveyed woredas.

Weed control

Hand weeding is the most widely practiced weed control method in Arsi: 84% of the wheat growers in the region practiced hand weeding of wheat (Table 8). Of these farmers, only 29.6% weeded their wheat fields twice or more. Variation was observed in the frequency of hand weeding across the five woredas. More farmers in Etheya (53.6%) and Asasa (46.0%) implemented two hand weedings as compared to the dominant practice of a single hand weeding in the other areas. This might reflect a relatively high severity of weed infestation in these areas: a significant yield loss could occur if farmers neglected the second hand weeding.

About 63% of the wheat growers reported adoption of the herbicide 2,4-D for weed control (Table 9). Adopters applied a mean rate of 0.74 l of herbicide per ha of wheat; the weighted mean rate of herbicide application across all wheat growers was 0.46 l of product per ha of wheat. The highest rate of herbicide usage, 94.8%, was reported in Lole followed by Etheya (77.2%) and Asasa (67.2%). In Arsi, about 50.8% of the herbicide adopters applied 2,4-D herbicide on their wheat fields at suboptimal rates between 0.13 and 0.5 l/ha of product, while the remaining adopters applied 2,4-D at a rate > 0.5 l/ha.

Factors Influencing Technology Adoption

Fertilizer adoption

The results of the logistic regression model (Table 10) revealed that the probability of a farmer adopting fertilizer is affected positively and significantly ($P<0.05$) by access to credit; the effect of access to extension services was positive and close to significance at the 10% level. The odds ratio also indicates that there is more than a three-fold chance of adopting fertilizer if the farmer is literate, under conditions of timely fertilizer delivery, and if the farmer owns a radio. The remaining variables, which had been expected to influence the probability of fertilizer adoption, were not significant at the 10% probability level.

The interaction of wheat area by variety, although not significant, was positively associated with the adoption of fertilizer: farmers sowing larger areas of improved wheat varieties are more likely to use fertilizer than other farmers. Radio ownership positively influenced the likelihood of adopting fertilizer; ownership of a radio increases farmer awareness through the dissemination of information. Land size was negatively associated with fertilizer use. It is plausible that farmers with small land holding increase their wheat production through intensive application of modern inputs like fertilizer.

Adoption of improved wheat varieties

The logistic regression results revealed that literate farmers are significantly ($P<0.1$) more likely to adopt improved varieties. Use of herbicide is also associated positively and significantly ($P<0.01$) with the probability of adopting improved wheat varieties, probably reflecting the fact that herbicides are often extended as one of the components of the improved technology package. Oxen number and fertilizer use exhibited a positive influence on the adoption of improved varieties, but these variables were not significant at the 10% probability level. The use of fertilizer increases the probability of adopting improved

varieties by two-fold. Extension contact, although not significant, influenced the adoption of improved varieties positively. The other variables, which were expected to influence the probability of adoption of improved varieties, were not significant at the 10% probability level.

Herbicide adoption

The logistic regression analysis showed that farmers planting larger areas of wheat are significantly ($P<0.01$) more likely to adopt herbicide than those with smaller areas. Moreover, the adoption of improved varieties was positively and significantly ($P<0.05$) associated with the adoption of chemical weed control. Access to credit and education level also affected the probability of adopting herbicide significantly ($P<0.05$) and positively: farmers who are literate and have access to credit are more likely to use herbicide. These four significant variables possessed the expected positive sign. The other variables, which had been expected to affect the probability of herbicide adoption, were not significant at the 10% probability level.

CONCLUSIONS

The large family size of the typical farm household in conjunction with the characteristically small land holdings necessitate the intensification of crop production through the application of improved agricultural technologies (i.e., HYVs, fertilizer, herbicides, and other improved agronomic practices). However, the expected productivity change is often influenced by factors which enhance or inhibit the adoption of improved production technologies. As the study results indicated, institutional variables (i.e., access to credit, extension, farmer education level, timeliness of input delivery) were often found to exert a critical influence on the adoption of bread wheat production technologies in Arsi Zone. Therefore, any attempt to promote the use of these technologies must focus on these institutional factors. In this regard, the current production package approach in Ethiopia, which includes the necessary support services (i.e., information, credit, etc.), should be extended in scope in order to have a significant impact on the production and productivity of wheat in Ethiopia.

The current study also revealed that farmers are using sub-optimal levels of some components of the recommended technology packages. Again, this can mainly be attributed to socio-economic constraints which confront the farmers. Therefore, there is a need to develop technology packages with alternative optimal options that can be adopted by farmers from different socio-economic strata under different agro-ecological conditions.

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Questions and Answers:

Omer H. Ibrahim: What is the farmer philosophy behind growing more than two cultivars?

Answer: Farmers try to diversify their cultivars for different reasons: disease risk, varietal preference, marketing issues, etc.

Omer H. Ibrahim: Can you elaborate on weed control in wheat with reference to sowing method, time of hand weeding, practicality and effectiveness of hand weeding in wheat?

Answer: Farmers often use a high seed rate to overcome weed competition. Hand weeding is the most effective method of weed control, provided that there is adequate family labor. However, hand weeding will be difficult during peak seasons due to overlapping activities.

Omer H. Ibrahim: The adoption rate of DAP was very high, but that of urea was very low. What are the possible reasons for that?

Answer: Farmers perceived that DAP increased grain yield while urea increased vegetative growth.

Table 1. Basic characteristics of the surveyed households (mean values).

Characteristic	Woreda					Overall mean
	Asasa	Bekoji	Etheya	Lole	Robe	
Family size	7.1	7.4	5.9	7.3	7.0	6.9
Age/Household heads	44.6	47.3	49.9	47.3	45.6	46.9
Male-headed Households (%)	73.3	81.7	80.0	91.7	88.3	83.0
Female-headed Households (%)	26.7	18.3	20.0	8.3	11.7	17.0
Educational level						
• Illiterate (%)	57.9	53.4	55.9	50.8	51.7	53.9
• Read and write (%)	10.5	27.6	23.7	20.3	25.0	21.5
• Primary school (%)	21.1	15.5	15.3	16.9	16.7	17.1
• Secondary school (%)	10.5	3.4	5.1	11.9	6.7	7.5

Source: Survey data, 1999

Table 2. Land holdings and livestock ownership, Arsi Zone, 1998.

Land holdings (timad†)	Woreda					Overall mean
	Asasa	Bekoji	Etheya	Lole	Robe	
Owned	11.76 (60)	14.27 (60)	7.48 (60)	10.10 (60)	9.97 (60)	10.70 (300)
Fallow	2.96 (34)	2.86 (32)	0.63 (2)	2.37 (38)	1.0 (2)	2.64 (108)
Grazing	3.83 (30)	5.26 (40)	1.15 (37)	2.18 (17)	2.77 (50)	3.13 (174)
Shared-out	3.67 (3)	3.0 (9)	3.0 (2)	3.5 (6)	2.0 (9)	2.86 (29)
Rented-out	4.89 (9)	2.33 (3)	1.94 (13)	2.78 (9)	1.88 (4)	2.86 (38)
Rented-in/crop production	3.95 (16)	4.12 (17)	5.22 (15)	9.2 (10)	2.13 (8)	4.86 (66)
Rented-in/grazing	3.67 (18)	4.38 (20)	1.53 (8)	3.0 (8)	2.22 (9)	3.33 (63)
Shared-in	2.64 (11)	2.57 (7)	1.71 (6)	3.0 (2)	1.95 (11)	2.29 (37)
Livestock (weighted mean)						
Total livestock units (TLU)	9.75	8.94	4.90	8.78	7.14	7.90
Oxen (number)	2.05	2.15	2.06	2.28	2.08	2.13

† 1 timad ≈ 0.25 ha

Note: Figures in parentheses indicate the numbers of respondents

Source: Survey data, 1999

Table 3. Wheat variety adoption (% of growers), Arsi Zone, 1998.

Variety	Asasa	Bekoji	Etheya	Lole	Robe	Mean
Wheat growers (%)	97	93	95	97	95	95
Kubsa (HAR1685)	44.1	13.7	71.9	42.4	21.1	39.2
Pavon-76	28.8	--	22.8	61.0	8.8	25.1
Batu	3.4	--	35.1	5.1	3.5	9.5
Enkoy	--	3.9	--	--	1.8	1.1
Dashen	15.3	37.3	3.5	--	--	10.6
Local	--	2.0	--	--	38.6	8.1
Wabe (HAR710)	33.9	9.8	8.8	22.0	--	15.2
K6290-Bulk	--	18.0	--	--	21.1	4.2
Galama (HAR604)	1.7	17.6	1.8	--	--	3.9
Mitike (HAR1709)	1.7	--	1.8	--	3.5	1.4
ET-13	1.7	35.3	--	--	22.8	11.3
K6295-4A	--	2.0	--	--	--	0.4
Israel	--	2.0	--	--	--	0.4

Source: Survey data, 1999

Table 4. Mean area and yield of adopted wheat varieties (per respondents producing each variety), Arsi Zone, 1998.

Variety	Asasa		Bekoji		Etheya		Lole		Robe		Mean	
	Area† (timad)	Yield† (qt/ha)	Area (timad)	Yield (qt/ha)	Area (timad)	Yield (qt/ha)	Area (timad)	Yield (qt/ha)	Area (timad)	Yield (qt/ha)	Area (timad)	Yield (qt/ha)
Kubsa	4.6	14.4	2.1	12	3.9	18.6	4.8	20	2.3	13.3	4	16.8
Pavon-76	3.7	16	--	--	2.2	16.7	6.5	21.7	2.9	16.6	4.8	19.2
Batu	3.5	22.5	--	--	3.8	18.3	3	10	1.5	5.5	3.5	16.8
Enkoy	--	--	2	14	--	--	--	--	3	--	2.3	14.0
Dashen	4.8	18	2.7	17	2.5	12	--	--	--	--	3.3	17.0
Local	--	--	1	10	--	--	--	--	3	11.7	2.9	11.6
Wabe	4.1	13	1.8	17	2.2	13.2	3.9	20.3	--	--	3.5	15.4
K6290-Bulk	--	--	--	13	--	--	--	--	--	--	--	12.9
Galama	3	20	1.8	12	2	16	--	--	--	--	1.9	13.1
Mitike	3	14	--	--	2	--	--	--	1.5	9	2	10.7
ET-13	2	13	2.3	10.2	2.3	--	--	--	2.4	8	2.3	9.6
K6295-4A	--	--	--	12	--	--	--	--	--	--	--	12.0
Israel	--	--	--	8	--	--	--	--	--	--	--	8.0

† 1 timad ≈ 0.25 ha; 1 qt/ha = 100 kg/ha.

Source: Survey data, 1999

Table 5. Number of wheat varieties produced, Arsi Zone, 1998.

Number of varieties	Per cent of respondents					
	Asasa	Bekoji	Etheya	Lole	Robe	Mean
1	72.9	80.4	59.6	71.2	80.7	72.8
2	23.7	17.6	35.1	27.1	17.5	24.4
3	3.4	2.0	5.3	1.7	1.8	2.8
Average	**1.3**	**1.2**	**1.5**	**1.3**	**1.2**	**1.3**

Source: Survey data, 1999

Table 6. Fertilizer rates adopted for wheat production, 1998.

Fertilizer	Asasa		Bekoji		Etheya		Lole		Robe		Mean	
	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea
Adoption rate (%)	100	22.4	75.0	5.4	100	61.4	100	19.0	82.5	23.0	92.3	26.0
Fertilizer rate (kg/ha)												
20-25 (% of adopters)	--	7.7	7.1	33.3	--	5.7	--	--	15	15.4	3.8	8.0
26-50 (% of adopters)	46	53.8	9.5	--	3.5	45.7	--	36.4	23.4	69.2	16.7	48.0
51-75 (% of adopters)	18.6	7.7	4.8	--	7	8.6	5.1	9.1	17	--	10.6	6.7
76-100 (% of adopters)	25.4	30.8	64.3	66.7	61.4	31.4	94.9	54.5	40.4	15.4	57.6	33.3
>100 (% of adopters)	10	--	14.3	--	28.1	8.6	--	--	4.2	--	11.3	4.0
Mean rate (kg/ha)	79.2	62.5	93.1	75.0	107.7	70.8	98.7	79.5	70.0	49.7	90.3	67.2
Weighted mean (kg/ha)	79.2	14.0	69.8	4.0	107.7	43.5	98.7	15.1	57.8	11.4	83.3	17.5

Source: Survey data, 1999

Table 7. Method of DAP and urea application, Arsi Zone, 1998.

	Per cent of respondents			
	At planting		Top dressing	
	DAP	Urea	DAP	Urea
Asasa	100	100	--	--
Bekoji	100	7.7	--	92.3
Etheya	100	92.6	--	7.4
Lole	98	95.8	2.0	4.2
Robe	100	--	--	100
Mean	99.5	68.1	0.5	31.9

Source: Survey data, 1999

Table 8. Hand weeding frequency, 1998.

Weeding	Asasa	Bekoji	Etheya	Lole	Robe	Mean
Adoption rate (%)	88.0	64.3	98.0	88.0	80.7	84.0
Weeding frequency						
1 (% of adopters)	54.0	86.5	41.1	92.0	87.2	70.4
2 (% of adopters)	46.0	10.8	53.6	6.0	12.8	27.5
3 (% of adopters)	--	--	3.5	2.0	--	1.3
4 (% of adopters)	--	2.7	--	--	--	0.4
5 (% of adopters)	--	--	1.8	--	--	0.4
Mean frequency	1.6	1.2	1.7	1.2	1.0	1.4

Source: Survey data, 1999

Table 9. Herbicide rates used by farmers, 1998.

Herbicide	Asasa	Bekoji	Etheya	Lole	Robe	Mean
Adoption rate (%)	67.2	30.4	77.2	94.8	42.0	62.6
Rate (l/ha)						
0.13-0.25 (% of adopters)	2.6	5.9	13.6	--	20.8	7.2
0.26-0.50 (% of adopters)	59	53	47.7	21.8	54.2	43.6
0.51-0.75 (% of adopters)	2.6	17.6	7	--	4.2	4.5
0.76-1.00 (% of adopters)	28.2	23.5	22.7	76.4	20.8	40.2
>1.00 (% of adopters)	7.6	--	9	1.8	--	4.5
Mean rate (l/ha)	0.74	0.62	0.68	0.91	0.55	0.74
Weighted mean (l/ha)	0.50	0.19	0.52	0.86	0.23	0.46

Source: Survey data, 1999

Table 10. Estimated coefficients of logistic regression for fertilizer adoption, Arsi Zone, 1998.

Variable	B	S.E.	Sig.	Exp(B)
Age	.0048	.0377	.8988	1.0048
Credit access	1.8528*	.8418	.0277	6.3778
Education	1.4092	1.2901	.2747	4.0926
Extension contact	1.9257	1.1909	.1059	6.8598
Timeliness (fertilizer delivery)	1.2782	1.1414	.2628	3.5900
Radio ownership	1.2618	1.4402	.3810	3.5317
Gender of household head	-10.9563	29.7639	.7128	.0000
Livestock (TLU)	-.0455	.0786	.5632	.9555
Family size	.0195	.1623	.9043	1.0197
Land size (owned)	-.1502	.1035	.1469	.8606
Wheat area * Variety	.1859	.1511	.2185	1.2043
Constant	11.5086	29.9106	.7004	

* indicates significance at the 5% probability level.
Model $\chi^2 = 24.31$ (sig. at 5% level); overall cases correctly predicted: 97.13%.

Table 11. Estimated coefficients of logistic regression for adoption of improved varieties[a], Arsi Zone, 1998.

Variable	B	S.E.	Sig.	Exp(B)
Age	.0107	.0106	.3115	1.0108
Education	.6329†	.3756	.0920	1.8830
Extension contact	.2151	.6300	.7328	1.2400
Radio ownership	-.3724	.3481	.2847	.6891
Family size	-.0049	.0556	.9302	.9951
Land size (owned)	-.0032	.0291	.9121	.9968
Herbicide use	.8065**	.3021	.0076	2.2401
Fertilizer use	.8029	.6141	.1910	2.2320
Oxen number	.1937	.1263	.1250	1.2137
Gender of household head	-.1008	.3858	.7939	.9041
Constant	-2.1616*	.9425	.0218	

**, * and † indicate significance at the 1, 5 and 10% probability levels, respectively.
Model $\chi^2 = 23.24$ (sig. at 1% level); overall cases correctly predicted: 63.30%.
[a]Varieties released since 1990.

Table 12. Estimated coefficients of logistic regression for herbicide adoption, Arsi Zone, 1998.

Variable	B	S.E.	Sig.	Exp(B)
Age	-.0062	.0120	.6042	.9938
Education	.8860*	.4252	.0372	2.4254
Radio ownership	.2363	.4075	.5621	1.2665
Family size	.0300	.0655	.6464	1.0305
Land size (owned)	-.0558	.0372	.1342	.9458
Gender of household head	-.3026	.4073	.4575	.7389
Credit access	.7874*	.3729	.0348	2.1976
Livestock (TLU)	.0358	.0346	.3005	1.0365
Wheat variety (improved)	1.4269*	.5791	.0137	4.1659
Area wheat	.3069**	.0692	.0000	1.3592
Constant	-2.2446*	.9443	.0175	

** and * indicate significance at the 1 and 5% probability levels, respectively.
Model $\chi^2 = 56.13$ (sig. at 1% level); overall cases correctly predicted: 73.31%.

FARMER PARTICIPATORY EVALUATION OF BREAD WHEAT VARIETIES AND ITS IMPACT ON ADOPTION OF TECHNOLOGY IN WEST SHEWA ZONE OF ETHIOPIA

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ABSTRACT

Eight spring bread wheat varieties were evaluated at Guder in 1997 and 1998 to assess their adaptation to the area and to document farmers' preferences. During evaluation of the varieties by farmers and researchers, two quantitative, viz., grain and biomass yield, and five qualitative, viz., grain size, taste of bread, threshing ability, seed color and baking quality, parameters were considered. Combined analyses of variance revealed that Galama yielded significantly higher than the local check "Dashen". Although statistically non-significant, Kubsa and Mitike outyielded Dashen by 4.2 and 0.4%, respectively. In terms of biomass yield, none of the improved varieties differed significantly from the local check. Results of the weighted direct matrix ranking indicated that Galama is the variety most favored by farmers followed by Kubsa. Demonstration of Galama was started during 1998 on 47 farmers' fields. A follow up study found that over 200 farmers were growing Galama during 1999. Farmer-based seed production and distribution played a major role in disseminating this variety. This paper, therefore, emphasizes the need to enhance farmer participation to facilitate technology adoption by stakeholders.

INTRODUCTION

Wheat is one of the major cereal crops in the Ethiopian highlands (Abebe, 1986; Hailu, 1991; Abera, 1991; NSIA, 1998) which range between 6 and 16° N, 35 and 42° E, and from 1500 to 2800 m a.s.l in altitude (IAR, undated). Peasants who provide about 93% of the national grain production produce wheat and other grains mainly for subsistence. Only 18.5% of all grain and 19.4% of wheat production is enters the market (Adanech, 1991).

Wheat dominates the food habits and dietary practices of the highlands population of Ethiopia. It can be roasted to serve as a snack or in between meals, boiled to serve as nifro (boiled grain), fermented to serve as injera (pancake like traditional bread) and dabo (local bread), prepared as a porridge and kitta (unfermented bread) and blended with other cereals form composite flours or incorporated into weaning food for children (Abera, 1991).

Moreover, wheat straw is one of the most important cereal straws produced in the mid altitude and highland areas of Ethiopia and is used for different purposes. The main use is as livestock feed particularly during the dry season but other uses include thatching, bedding material, maintenance of soil fertility (being plowed back into soil), and industrial uses (e.g. ,

paper products, hardboard, egg trays, and for packaging in the glass industry) (Said and Adugna, 1991).

Wheat being one of the major crops grown in the study area, it is characterized by low production and productivity per unit area. Results of base line survey conducted in 1992/93 (unpublished data) by Birbirsa and Cherecha Development Program of Ethiopia Rural Self Help Association (BCDP of ERSHA) revealed that one of the limiting factors contributed to low yield of wheat may be using the same variety year after year. Even though farmers in the area were provided with improved variety of wheat, ET-13, through the government extension package program, they were complaining about this variety, for it demands high labor especially during threshing and is poor in grain size. Alternate varieties were not introduced thereafter.

The subjectively assessed characters of appearance play a part in evaluating general quality of the grain (Kettlewell, 1989). Farmers evaluate varieties of wheat from different angles. However, the national wheat improvement program has been releasing a number of high yielding wheat varieties with wide geographical adaptation (Bekele *et al.*, 1994) without considering some qualitative aspects, which are of farmers' interest. Researchers, compared with the attainment of high yield, have neglected the achievement of bread making quality by farmers, for example.

Therefore, the objective of this work was to evaluate the adaptability and acceptability of bread wheat varieties (released for wide adaptation) from farmers' perspective in West Shewa zone of Ethiopia.

MATERIALS AND METHODS

Eight bread wheat varieties (Table 2) currently under production in the country were sown on six farmers' fields at Gudar woreda, West Shewa zone of Ethiopia in collaboration with Holetta Agricultural Research Center (HARC) and a local NGO (ERSHA), for two cropping season (1997 and 1998). Since there was a complete devastation of the varieties by Chaffer grub, 'Guguba' in local Oromipha language, and cattle on two and one of the farms, respectively, we used the remaining three farms for the analyses. Each farmland was considered as a replication. Seed and fertilizer rate of 175 and 60:69 kg $N:P_2O_5$ /ha respectively, and plot size of 5 x 5 m were used.

In a field day organized by the NGO in 1997, farmers and researchers were involved. In that day, farmers evaluated the varieties qualitatively, i.e., by their seed color and size (plumpness), threshing ability, taste of bread and baking quality. Quantitative data taken at harvest, which include grain and biomass yields were also considered. Homemade breads were prepared from each of the varieties by a single female following uniform procedure. First the grains were ground using traditional grinding stone. Then the dough was prepared using traditional fermenting agent (Ersho in Amharic) as yeast in that portion of the flour was mixed with Ersho and kept overnight. In the morning when the dough fermented/raised, the remaining flour was added and left until re-fermentation takes place. Then it was baked in an open fire using again traditional stove, "Geber-mitad" in Amharic. The farmers were asked to rank their criteria according to their importance in consensus, and to numerically rate the varieties from 1-10 (where 10 refers to the best and 1 refers to the poor) across each qualitative criterion. Although all the varieties are white, the farmers gave different scores or rank. For the quantitative parameter, ranks (the lowest number the best) were given to the

varieties based on the mean yield value. In order to combine all parameters, numerical ratings were converted into rank.

RCBD method of statistical analysis was employed to analyze quantitative data, and a modified Participatory Rural Appraisal (PRA) technique for prioritization (Anonymous, undated), i.e., weighted direct matrix ranking, was used to differentiate farmers' favorite variety considering both qualitative and quantitative criteria. Simple correlation analysis was also used to see interdependence between the variables based on the farmers' preference rank.

RESULTS AND DISCUSSION

Combined analysis of variance revealed that Galama gave significantly higher grain yield (2.9 t/ha) among the eight varieties. The rest of the varieties had statistically equivalent grain yield except the difference found between Kubsa and Tusie. Although statistically non-significant, Kubsa and Mitike outyielded the local check (Dashen) by 4.2 and 0.37% respectively. As far as biomass yield is concerned, Galama stood first though the mean yield difference with four of the entries including the local check was not significant. Biomass yield of Wabe and Tusie significantly differed from that of Galama, Kubsa and Mitike, and Abolla had the same as Galama (Table 2). Unlike the case of grain and biomass yield, harvest index of the varieties were not significantly different (Table 6). Mean values of harvest index indicated that Galama still outsmarted all varieties (Table 2).

The mean values of weighted direct matrix ranking for all qualitative and quantitative parameters considered showed that all the new varieties except Tusie outweighed the local check (Dashen). Farmers' preference order to the varieties in the final assessment indicated that Galama was the favorite variety followed by Kubsa, Mitike, ET-13, Wabe, Abolla, Dashen and Tusie (Table 3).

The farmers were highly impressed by the vegetative growth of Kubsa and Wabe at their early growth stage, as the two varieties were vigorous in growth and early to medium maturity types. However, later on Galama came out with the best agronomic performance, which the farmers believed to substitute Dashen, their favorite 'local' cultivar. It was characterized by the farmers as having high tillering capacity, superior growth, big panicle, easy threshing ability, superior yield, large grain size and plumpness, better dough and bread qualities.

As grain yield has been the prime selection criteria for the resource-poor subsistence farmers in the study area in particular and in the peasantry in general, it might have biased the farmers during evaluation of varieties. Thus, qualitative data were analyzed independently to assess the position of the varieties against other farmers' criteria so that breeders could get feedback as to a trait for future improvement. As a result, change in priority order was observed for all varieties except Galama. The preference sequence from best to poor cultivar was Galama, Wabe, Abolla/Tusie, Kubsa, Dashen, ET-13 and Mitike. Variety Wabe took the second position because of its good seed color and threshing ability. Similarly, Tusie and Abolla were in relatively good rank for their good grain size and in addition good taste of bread for the latter. Kubsa was in the fifth preference rank mainly due to its bad dough and loaf quality. The local check was pushed one step up because of its fair threshing ability and grain size. Although Mitikie was the third important variety in the overall evaluation (Table 3) due to its baking quality/taste of bread and yield, it took the last order in this case, for it had small grain size and difficulty during threshing like ET-13 (Table 4). Similar complaints were found for

ET-13 in an informal survey conducted by research-extension department of HARC around Wolmera woreda.

Although Galama did not express its real yield potential on farmers' fields probably due to poor management practice and pest problem, it is a high yielding variety. High yield cannot be recombined with high protein content (Loffler *et al.*, 1985; Akmal Khan *et al.*, 1986; Blum *et al.*, 1987; Kettlewell, 1989) which determine baking quality. Unpublished preliminary study on Ethiopian bread wheat varieties has also revealed that Galama had high mixogram development time, low flour protein and low loaf volume, which are all indicators of poor baking quality. However, these results were contradictory with the findings in homemade bread quality assessment in the study area. The baking procedure might influence the quality of the bread. This calls researchers to do more investigation in the future.

Results of simple correlation analysis indicated that there was strong positive correlation between grain yield and biomass yield (r =0.952), baking quality and taste of bread (r = 0.810) and threshing ability and seed color (r = 0.748) (Table 5).

All in all, farmers' evaluation and yield analysis indicated that variety Galama was superior over the others in this test followed by Kubsa. Based on the year 1977 assessment, many farmers were very interested and requested BCDP to provide them with seed of Galama. Few farmers were also interested on Kubsa and Wabe. Even though it is hard to depend on the results of one year, it was difficult to resist the strong demands of the farmers. Hence, BCDP was convinced and agreed to provide them with the requested seeds, and to further test performance on larger plots under crop variety popularization scheme. Accordingly, Galama, Kubsa and Wabe varieties were demonstrated on 47, 3 and 2 farmers' plots of 0.25 ha respectively in 1998. Kubsa was favored by the farmers in lower 'Dega' agro climatic zone (mid highland = 2000 – 2300 m a.s.l.), and Galama adapted very well and was very much liked in the upper "Dega" (highland areas > 2300 m). Follow up activity as to the fate of variety Galama was made in 1998. Accordingly, it was found that over 200 farmers were involved in 1999. Farmer based seed production and circulation system played a great role in disseminating this variety. It has been replacing all other varieties in the region.

Generally, it was felt that this on-farm trial was found useful and helpful, and experiences were gained in selecting farmers for participation, planning, implementing and analyzing the results. We feel that it is important to pinpoint the fear concerning variety diversification. As you may know, among other socio-economic factors, the dynamicity mainly in pathogen conditions in Ethiopia urges researchers to put their effort for a relatively faster replacement of varieties than most of the other wheat growing countries. Thus, it is impossible to rely on a given variety that might be suitable to an environment under the existing conditions, for tomorrow's fate is unforeseen. Thus, new varieties of wheat should be released in the study area in order to come up with alternate cultivars to Galama.

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Questions and Answers:

Efrem Bechere: Do you think that farmers and urban consumers have the same taste criteria for bread?

Answer: I don't think so, because baking procedures and additives prevail in the urban sector.

Table 1. List of bread wheat varieties used for evaluation with their pedigree, seed color, year of release and production status.

Variety	Cross/pedigree	Days to maturity	Seed color	Year of release	Production status *
Galama	4777* 21/FLN/GB/3/PVN	135	White	1995	WG
Kubsa	ATTILA	131	"	1994	WG
Dashen	KVZ/BUHO//KAL/BB	136	"	1984	WG
Mitike	BOW28 X RBC	135	"	1993	WG
Abolla	SERI/BOW"S"/BUC"S"	130	"	1996	EXPA.
Wabe	MAIORAL/BUCKBUCK	130	"	1994	WG
Tusie	COOK/VEE"S"//DOVE"S"	127	"	1996	EXPA.
ET-13	ENKOY/UQ105	132	"	1981	WG

WG = widely grown; EXPA = Expanding
* = adapted from: Payne *et al.* (1996).

Table. 2 Mean values of grain and biomass yield and harvest index of the eight Ethiopian bread wheat varieties at Gudar, 1997-98.

Variety	Grain yield (t/ha)	Biomass yield (t/ha)	Harvest index
Galama	2.893 a*	7.280 a*	0.397
Kubsa	2.552 b	6.818 ab	0.372
Dashen	2.449 bc	6.503 abc	0.377
Mitike	2.458 bc	7.065 ab	0.351
Abolla	2.192 bc	6.312 bc	0.344
Wabe	2.242 bc	5.888 c	0.384
Tusie	2.117 c	5.835 c	0.363
ET-13	2.362 bc	6.458 abc	0.362
Mean	2.408	6.520	0.369
S.E.	0.1155	0.2649	0.0129
LSD(0.05)	0.3345	0.7644	0.0374
C.V.(%)	11.77	9.96	8.82

Means followed by the same letter are not significantly different at P = 0.05.

Table 3. Preference and weighted rank of the varieties for the different qualities ranked by the farmers.

Variety	1 GY	2 GS	3 TB	4 TH	5 SC	6 BQ	7 BY	Sum of rank	Mean	Priority order
Galama	1	2	6	4	20	6	7	46	6.57	1
Kubsa	2	10	18	12	10	42	21	115	16.43	2
Dashen	4	8	24	8	15	48	28	135	19.29	7
Mitike	3	14	9	24	30	24	14	118	16.86	3
Abolla	7	6	12	16	35	12	42	130	18.57	6
Wabe	6	12	15	4	5	36	49	127	18.14	4
Tusie	8	4	21	20	25	30	56	164	23.43	8
ET-13	5	14	3	24	30	18	35	129	18.43	5

GY = grain yield; GS = grain size; TB = taste of bread; TH = threshing ability; SC = seed color; BQ = baking quality; BY = biological yield.

Table 4. Preference and weighted scores of the varieties against each and all qualitative parameters as given by the farmers.

Variety	5 GS	4 TB	3 TH	2 SC	1 BQ	Sum of scores	Mean	Priority order
Galama	50	36	30	14	10	140	28.00	1
Kubsa	25	20	24	18	3	90	18.00	4
Dashen	30	12	27	16	2	87	17.40	5
Mitike	15	32	9	10	7	73	14.60	7
Abolla	35	28	18	4	9	94	18.80	3
Wabe	20	24	30	20	5	99	19.80	2
Tusie	45	16	15	15	12	94	18.80	3
ET-13	15	40	9	10	8	82	16.40	6

Table 5. Results of simple correlation analysis on weighted rank of the seven selected criteria.

	GY	GS	TB	TH	SC	BQ	BY
GY							
GS	-0.039						
TB	0.286	-0.245					
TH	0.310	0.412	-0.282				
SC	0.275	-0.052	-0.467	0.748*			
BQ	0.048	0.296	0.810*	-0.197	-0.660		
BY	0.952**	-0.013	0.346	0.141	0.000	0.214	

*, ** Correlation coefficients significantly different from zero at 0.05 and <0.001 levels of probability, respectively.

Table 6. Results of ANOVA for grain and biomass yield and harvest index.

	F value	Probability	C.V.(%)
Grain yield			11.77
Year (Y)	0.9865	-	
Variety (V)	4.4990	0.0018	
Y x V	2.1687	0.0686	
Biomass yield			9.96
Year (Y)	0.3149	-	
Variety (V)	3.8226	0.0049	
Y x V	1.3383	0.2698	
Harvest index			8.82
Year (Y)	1.1702	0.3402	
Variety (V)	1.6978	0.1503	
Y x V	0.6191	-	

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